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JOURNAL OF THE AERONAUTICAL SCIENCES

CONTENTS

A Practical System of Radiometeorography . . . . L. F. Curtiss and A. V. Astin 35

On the Representation of a Ground in the Wind Tunnel . . . . . Masami Ono 40

Effect of Horizontal Variations in Center of Gravity Position on the Static Longitudinal Stability of Airplanes . . . . . William Jenney 43

Stability of Bars with Lateral and Axial Loading . . . . . Stewart Way 46

Notes on the Dust Storms of the Spring of 1935 with Particular Reference to Airplane Weather Observations and Air Navigation . . . . . L. T. Samuels 52

Further Investigation of the Pitot-Static Tube . . . . . Kenneth G. Merriam and Ellis R. Spaulding 55

Methods of Cabin Supercharging and Their Necessary Control Systems . A. L. Klein 58

Structural Features of Supercharged Cockpits and Cabins . . . . . J. E. Lipp 61

Rubber Substitutes as Coatings for Balloon Fabrics . . . . . Theron P. Sager 63

Book Reviews 65

Institute Notes 67

Classification of Articles 70

Advertising v

Volume 3 NOVEMBER, 1935 Number 2

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JOURNAL OF THE AERONAUTICAL SCIENCES

Volume 3 NOVEMBER, 1935 Number 2

A Practical System for Radiometeorography

L. F. Curtiss and A. V. Astin, *National Bureau of Standards**

(Received September 11, 1935)

Abstract

A DESCRIPTION is given of a complete system based on the Olland telemeteorograph, for obtaining meteorological and similar data from instruments attached to sounding balloons by means of a radio transmitter. In this way records are obtained instantaneously by a receiver located on the ground. A wavelength of 5 meters is used permitting convenient use of half-wave tuned doublet antennas for transmission as well as reception. The radio transmitter is "keyed" in such a way that signals are emitted only during several short contacts per minute, thus greatly reducing the size of the plate batteries required. Complete apparatus for attachment to balloon weighs less than 2 pounds and has been received clearly at altitudes of 23 kilometers (14.3 miles) and at distances of 80 miles. A method of direction finding for pulses used in this system is described.

Introduction

Although the general subject of telemeteorography is an old one it is only in recent years that considerable attention has been given to methods of recording meteorological observations by means of radio transmitters carried by sounding balloons arranged to broadcast readings of the instrument to a radio-recorder located on the ground. Such methods obviously have very great advantages over any others which have yet been developed. Among them are:

(1) An instantaneous record of the observations is made as fast as the balloon ascends. Recovery of balloon and equipment is not necessary to obtain the record as is the case when self-recording instruments are sent up.

(2) Records may be obtained in any kind of weather. This is not true of the most common method of observation used at present, that of taking instruments aloft in airplanes.

(3) Observations may be made easily to any altitude up to 20 kilometers. Airplanes usually ascend only to about 5 kilometers for weather observations.

(4) The equipment required is much less expensive and observations can therefore be obtained more cheaply than by use of airplanes.

In Germany, France, and Finland various successful methods have already been developed. Readers interested in the literature on this subject prior to 1934 are referred to a bibliography and historical summary published by Wenstrom.[1] In their approach to this problem the authors have departed from all methods which have thus far been applied to radiometeorography, within their knowledge, and reverted to the earliest telemeteorographic method of which a complete description is available. In 1877, Olland, a precision instrument maker of Utrecht, succeeded in designing and building a system by which an instrument with a barometer and an anemometer installed in the tower of the Cathedral of Utrecht produced automatically records of the readings in the office of the director of the Royal Meteorological Institute. This system is described by Snellen,[2] and represents the earliest successful telemeteorograph which has come to the authors'

* Publication approved by the Director of the National Bureau of Standards of the U. S. Department of Commerce.

[1] W. H. Wenstrom, *Radiometeorography as Applied to Unmanned Balloons*, Monthly Weather Review, Vol. 62, No. 7, pp. 221–226; July, 1934.

[2] M. Snellen, *Le Telemeteorographie D' Olland*, Archiv. Neerlandaises, Vol. 14, No. 2, pp. 180–208; 1879.

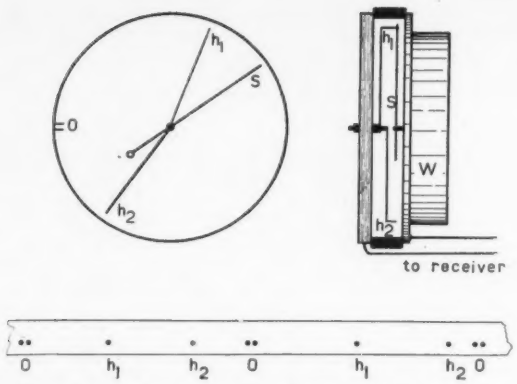


FIG. 1. A diagram showing the essentials of the Olland system of telemeteorography as modified by Moltchanoff.

attention. A simplification of the equipment required for this system has been sugested by Moltchanoff,[3] at a much later date. However, this method of telemeteorography has not yet been applied to a radio-transmitter carried by a sounding balloon, in spite of the fact that it seems remarkably well suited to this purpose. This article gives a description of the progress the authors have made in developing a radiometeorograph of this type.

A complete system of radiometeorography can be regarded as composed of three elements: (1) A telemeteorograph, (2) a radio transmitter and (3) a recording radio receiver. The telemeteorograph serves the purpose of "keying" the radio transmitter in such a way that the signals thus emitted will cause the recording receiver to produce a record which can be interpreted in terms of the calibration of the meteorological instruments attached to the telemeteorograph.

TELEMETEOROGRAPH

The essentials of the Olland system can be explained by referring to the diagram in Fig. 1. The circle at the upper left represents a plan of the indicating hands in which S is a sweep hand rotating uniformly. This hand is electrically insulated from the fixed contacts O and from the movable hands h_1 and h_2 except at the moment when the sweep hand passes, when a brief electrical contact is made. This can be seen more clearly from the diagram at the upper right showing a side view of the hands and contacts. W is the clock movement which drives the sweep hand, S. The arms h_1 and h_2 are each connected to some meteorological indicating element so that each hand moves over one-half the circumference of the circle for the full scale deflection of the associated element. Such an arrangement electrically connected to a recording telegraph receiver in the manner indicated would give a record of the type indicated at the bottom of Fig. 1, which shows a section of the recording tape. The double dots O, O, are repeated uniformly spaced corresponding to the contact of the sweep hand at O for each revolution. In between these reference marks the dots occurring at the contacts of the sweep hand, S, with h_1 and h_2 will be spaced in such a way that from measurements of the distances Oh_1 and Oh_2 the actual readings of the meteorological elements at the instant of contact can be obtained. If desired, movable hands can be added to be actuated by elements for indicating several meteorological factors. It can be seen at once that a telemeteorograph such as described above can easily be arranged to key a radio transmitter and produce a similar record through the medium of a recording radio receiver. Such a radiometeorograph would be in every way as accurate as the telemeteorograph used for keying.

In designing an actual telemeteorograph according to the outline given above for use with a radio transmitter the authors have restricted their attention to an instrument giving pressure and temperature indications. The most important factor to be considered in all this work is elimination of all unnecessary weight since the cost of balloons increases rapidly with size. For this reason a specially designed watch mechanism has been selected to drive the sweep hand. In this watch

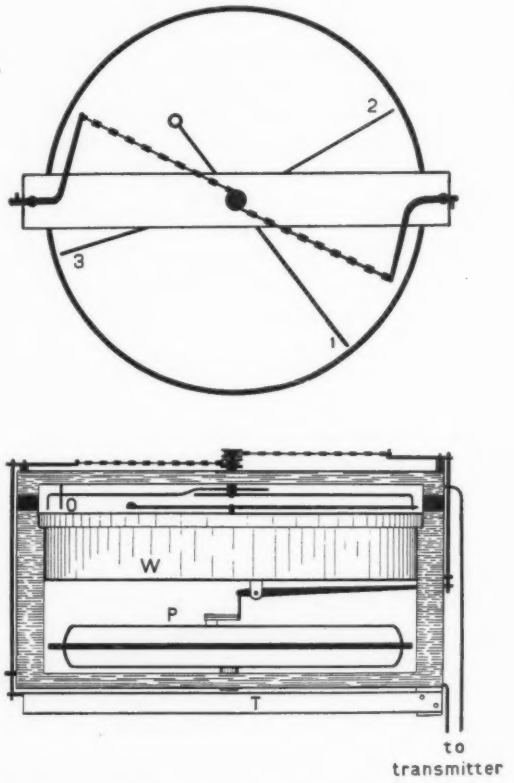


FIG. 2. Drawing of telemeteorograph for use with a radio transmitter attached to a sounding balloon.

[3] P. Moltchanoff, *Zur Technik der Erforschung der Atmosphare*, Beitr. Z. Phys. d. fr. Atm., Vol. 14, Nos. 1 and 2, pp. 39–51; 1928.

aluminum has been used wherever possible and the supporting frame work is of the same metal. The complete device is shown in Fig. 2. *W* is the watch mechanism, *P* the pressure element and *T* the thermal element. Hand 1 is the sweephand; hands 2 and 3 are connected to the pressure and thermal elements respectively. The double contact is shown at *O* which gives the reference marks for interpretation of the record. This device can be calibrated by means of a suitably arranged simple electrical circuit entirely independently of the radio-circuit to which it may be attached when in use. This calibration will be valid with any radio-circuit. This is an important advantage over those systems of radio-meteorography in which a variation of the emitted radio-frequency, or a modulation frequency is used as an indicator. Such arrangements must be calibrated with the radio-circuit with which they are intended to be used and any subsequent change in this circuit may impair the calibration. Furthermore, if this device is keyed to the radio-circuit in such a way that the transmitter is on only during the contact an enormous saving in plate battery drain is effected. For example, a transmitter using 50 milliamperes in the plate circuit during transmission connected to a telemeteorograph giving 5 contacts per minute each of 1/20 second duration, would subject the plate battery to a drain of only 25 milliampere *minutes* during a two hour flight of the balloon. This permits the use of relatively strong signals and a plate battery of very light weight. This arrangement is also favorable to the usual dry battery in that it allows the recovery of the battery during the "off" intervals insuring maximum output at the moment of contact.

As stated, the accuracy of this telemeteorograph is dependent upon the uniformity of rotation of the sweep hand. Since the required electrical contacts may be very light, they offer no difficulty. However, if exposed directly at altitudes of 40,000 feet where temperatures may be as low as —60°C., a watch mechanism would fail to maintain sufficient accuracy. Moreover, the dry batteries must also be protected from such low temperatures. This problem has been solved by inclosing the batteries, oscillator and telemeteorograph in a cellophane envelope with aluminum foil reflectors on the bottom, after the method of Regener and Pfotzer.[4] In this way the temperatures of the interior of the "hot house" can be easily maintained as high as 35°C during daytime observations. When temperature or other measurements outside this inclosure are desired, the indicating elements can be mounted outside and connected to the telemeteorograph through small openings in the cellophane.

[4] E. Regener & G. Pfotzer, *Messungen der Ultrastrahlung der Oberen Atmosphare mit den Zahlrohr*, Phys. ZS, Vol. 35, No. 19, pp. 779–784; Oct. 1, 1934.

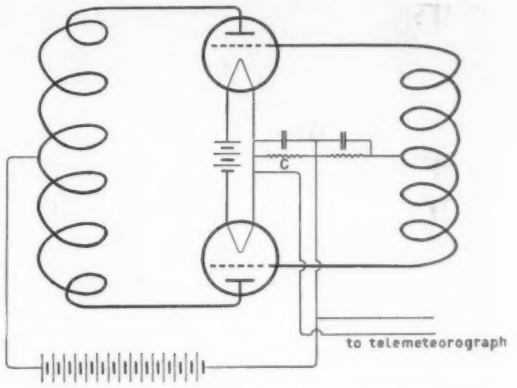


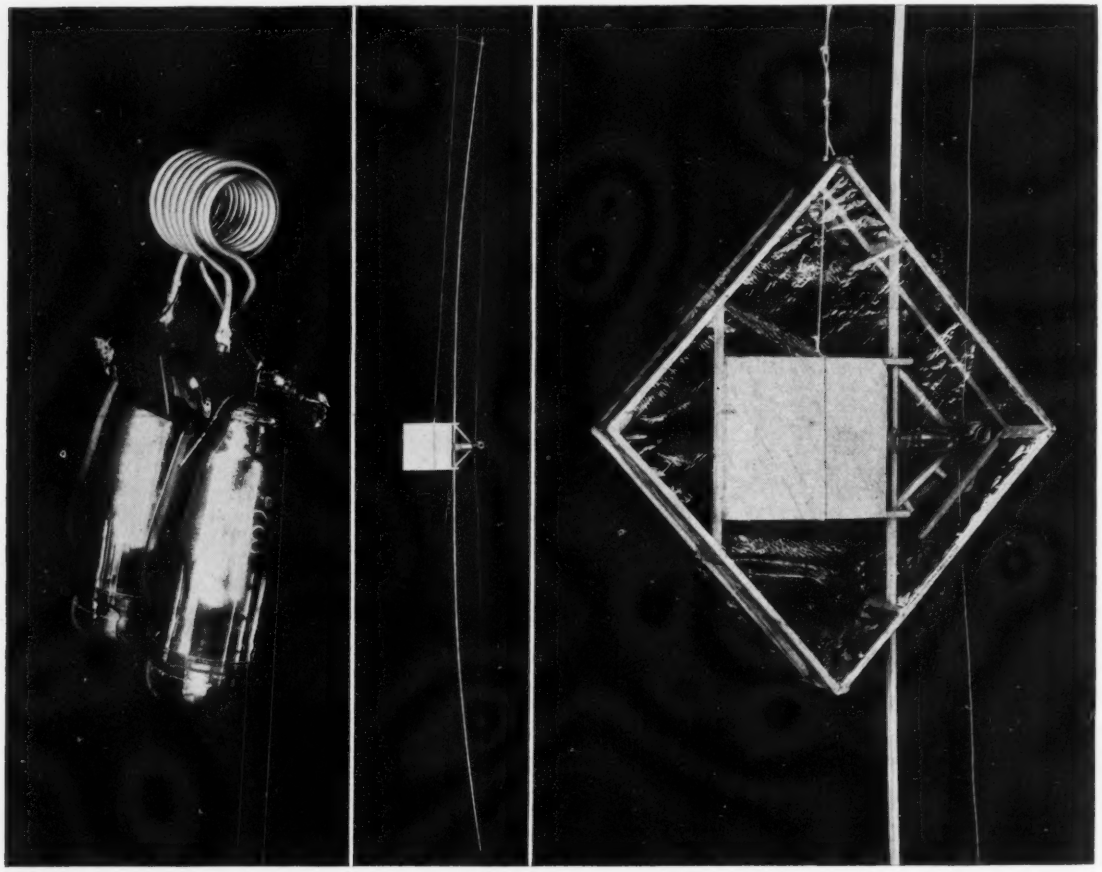
FIG. 3. Wiring diagram of the push-pull oscillator used in the balloon transmitter.

RADIO TRANSMITTER

In selecting a frequency band for radiometeorographs simplicity of construction led to the adoption of the 60 megacycle region for preliminary experiments. Such good results have been obtained that it seemed unnecessary to try other frequencies. It should be pointed out that the ultra-high frequencies are well suited to this work because of the absence of a reflected "sky wave" to complicate reception in producing fading and interfering with accurate direction finding. If one goes appreciably above 60 megacycles, however, difficulties are encountered in using ordinary commercial tubes, since the natural constants of such tubes play an important role in the oscillating circuits at these frequencies. The 60 megacycle region is free of this embarrassment while still retaining the advantage of using fairly short tuned half-wave doublet antennas and small coils and condensers thus reducing weight. In addition very sensitive receivers of simple design are already available at this frequency.

A push-pull oscillator, using two of the 30-type receiving tubes is used in the five-meter transmitter. These oscillators are more stable in frequency than single tube oscillators and are especially convenient since the two filaments provide the proper load for 3 dry cells when connected in series. Furthermore, the radio-frequency output of such an oscillator can be made relatively high by using a high plate voltage, particularly when signals are desired in short pulses so that there is no danger of overheating the plates. Moreover, the weight of the additional tube is small. The low filament drain of these tubes permits the use of small-size flashlight cells in the filament circuit.

The wiring diagram of these oscillators is shown in Fig. 3. No departure has been made from usual radio practice in the arrangement except to discard the usual plate tuning condenser, using the self-capacity of the coils and tube for this purpose. It has been found possible to adjust such a circuit very closely to the desired frequency without resort to a tuning condenser.



FIGS. 4, 5, 6. FIG. 4, photograph of the push-pull oscillator. FIG. 5, photograph of transmitter as suspended from a balloon. Cellophane inclosure omitted. FIG. 6, close view of mounted oscillator showing cellophane inclosure.

The plate and grid coils are close coupled (concentric). This is shown in the photograph in Fig. 4. The other feature of importance is the method of keying. The cathode-bias resistor, C, is of high enough resistance to prevent plate current from flowing. When the telemeteorograph is connected as indicated this resistor is shorted on each contact, permitting about 50 milliamperes to flow in the plate circuit. By introducing the telemeteorograph into the circuit in this way the contacts are always shunted by the resistor, C, and the voltage at the contacts is low, eliminating any danger of arcing or sparking. Also this arrangement prevents any undesirable change in the tuning as contacts are made and broken. The antenna for this transmitter consists of a single piece of aluminum wire 2.7 meters long which makes a single turn around the outside of the tuning coils. This wire is held taut by a light wooden bow as shown in the photograph in Fig. 5 which shows a transmitter without the cellophane inclosure. The antenna hangs vertically, and the receiving antenna is similarly mounted. Fig. 6 shows a close view of the mounted transmitter with the cellophane inclosure in place. The aluminum foil reflectors are removed in this view.

RECORDING RADIO RECEIVER

The receiver which has been used to date with greatest success is a resistance-capacity coupled intermediate frequency superheterodyne described by Jones.[5] A buffer stage using a 954 tube was introduced in the antenna circuit which reduces radiation from antenna and also gives a gain of about 4 in signal strength. Sufficient audio amplification was added to give positive action to a thyraton circuit operating a tape-punching mechanism to produce the record. Since the pulses from the radiometeorograph lend themselves readily to audio amplification, this was easily done.

This type of receiver is very well suited to this particular use. It combines the high sensitivity of a superregenerative receiver with a moderate selectivity such that the signal is never lost between pulses and can be retuned if necessary. In actual practice this has been found to be comparatively easy, the actual drifts in frequency being small enough that only a slight decrease in intensity is noted from pulse to pulse.

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[5] F. C. Jones, *A Simple Inexpensive 4-tube, 5-meter Superheterodyne*, Radio, Vol. 17, No. 3, pp. 16–17; March, 1935.

Since this drift is usually unidirectional, it is fairly simple by small adjustments to maintain signals at full volume. It should also be mentioned that such a receiver is simple and inexpensive to construct. It is convenient to use since only a single dial is required for tuning.

Direction Finding

Although little attention has been given to direction finding in any of the systems of radiometeorography hitherto proposed, the solution of this problem is relatively simple for those systems using a continuous signal. However, in the system just described some departure from the method of orienting the antenna for a position of minimum signal is necessary, because of the absence of a continuous signal. A modification of a method of Watson Watt[6] (who employed two crossed loop antennas and recorded observations on an oscillograph) should meet the requirements. The authors propose to use two horizontal half-wave doublets at right angles to each other, each connected to a separate receiver of identical gain. The output of each receiver is connected to a double pivot flux-meter which remains at the maximum deflection until reset to zero. Thus when a pulse comes in the two flux-meters simultaneously deflect and remain so until read and reset. The signal strength on each antenna varies according to direction so that the components along the two horizontal axes represented by the antenna are proportional to the deflections of the flux-meters. In this way the horizontal direction of arrival of each pulse may be obtained and the work of direction finding is actually simpler than in the case where a single pivoted doublet is used. Simultaneous observations at two receiving stations, each equipped with a direction finding system as outlined before will give data from which horizontal wind velocities may be computed.

[6] R. A. Watson Watt, *Directional Recording of Atmospherics*, J.I.E.E., London, Vol. 64, pp. 611–622; May, 1926.

Conclusion

Radiometeorographs, built as described above, have been sent up as high as 23 kilometers (14.3 miles) and followed by the receiving station with ease. In some cases these balloons have gone as far as 80 miles from the receiving station. In these tests the balloons were released 5 miles from the receiver since at this distance the initial conditions of reception approximate those obtaining throughout the observations. Flights have been made with the cooperation of the United States Weather Bureau and followed by them using two theodolites to check the radio-record. The farthest these balloons have gone is about 80 miles but it was apparent that these transmitters could be heard at least twice this distance if necessary. Outfits sent up so far have weighed 3 pounds. This weight is mainly in B batteries and can be greatly reduced as soon as batteries of small capacity are available. The smallest commercial battery so far obtained weighs 2 pounds for 135 volts and has a capacity of 200 milliampere hours, which is many times the required 25 to 50 milliampere *minutes*. When in addition filament batteries of the exact rating can be used the complete apparatus will weigh only a little over one pound.

In conclusion the authors wish to acknowledge the aid and cooperation of the United States Weather Bureau. They are especially grateful for the active interest taken by Mr. Gregg, the Chief of the Bureau, as well as for the benefit of frequent consultations with Mr. D. M. Little and Mr. L. T. Samuels. It is also a pleasure to thank Dr. T. H. Johnson of the Bartold Foundation and Mr Arthur Bent of the Blue Hill Meteorological Observatory for many helpful suggestions. Mr. L. L. Stockman and Mr. B. W. Brown gave considerable aid in constructing the apparatus used in these experiments.

On the Representation of a Ground in the Wind Tunnel

Masami Ono, *Kawanisi Aircraft Co., Ltd., Japan*

(Received August 7, 1935)

THE methods of representing the ground in wind tunnel work can be divided in the following three groups:

(1) The stationary plate. The surface of the plate near the model represents the ground, but the boundary layer along this surface may alter the flow configuration round the model. This method has been used extensively up to the present due perhaps to its simplicity and economy, only one model and a plate being necessary.

(2) The moving belt. The endless belt which represents the ground is run at the same velocity as the wind, thus preventing the formation of the boundary layer. If this could be carried out without mechanical difficulties, it would prove to be the most ideal method, but to prevent flutter of the belt when running at high speeds seems to be very difficult. A device which is claimed to have eliminated this flutter has recently been described in this Journal.[1]

(3) The image model method. Two models are placed symmetrically with respect to an imaginary ground plane. This method is as simple as that of (1) but is costly due to the need of an extra model. Moreover, it is often criticized as an insufficient method of representing the ground effect since the vortices behind each model cannot, in reality, arrange themselves symmetrically with respect to the ground plane.

The author has conducted a few experiments, chiefly of quantitative nature, to compare the flow configurations obtained by methods (1) and (3). The apparatus used was a small hand-driven water channel (Fig. 1) of about 20 cm. breadth with a flow velocity of about 10 cm. per sec. A thin wooden plate is placed behind the paddle with its upper face at about the same level as the still water surface. This plate serves to damp out the waves formed behind the paddle and it was found that a shallow zig-zag formed on the upper surface makes it still more effective for that purpose.

The models tested were (1) an automobile shape and (2) an airfoil section, and both have been tested near a wall by method (1) and with an image model by method (2) in the middle of the channel.

The usual method of taking photographs of flow patterns was employed using aluminum powder, but the time of exposure needed some consideration. Since the object of the photography is to obtain the eddies

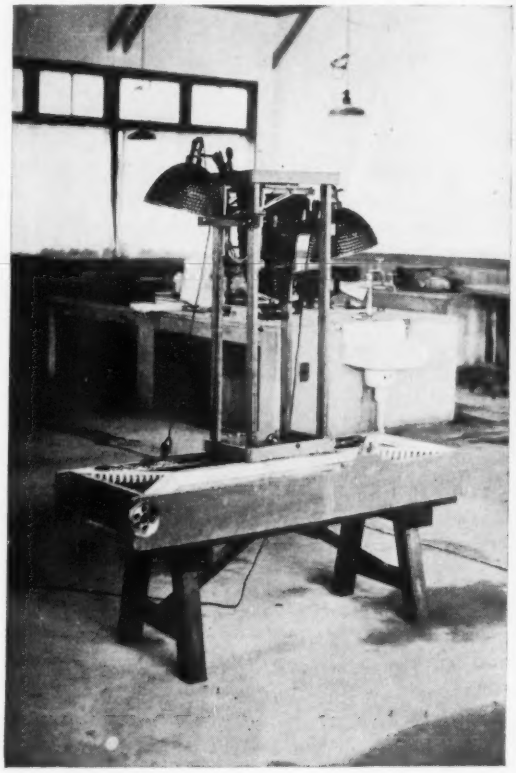


FIG. 1.

accompanying the flow, an instantaneous photograph (usually of 1/15 sec. exposure) may give only one phase of fluid motion and may not represent a time mean of motion which is considered to be more necessary for our present purpose.

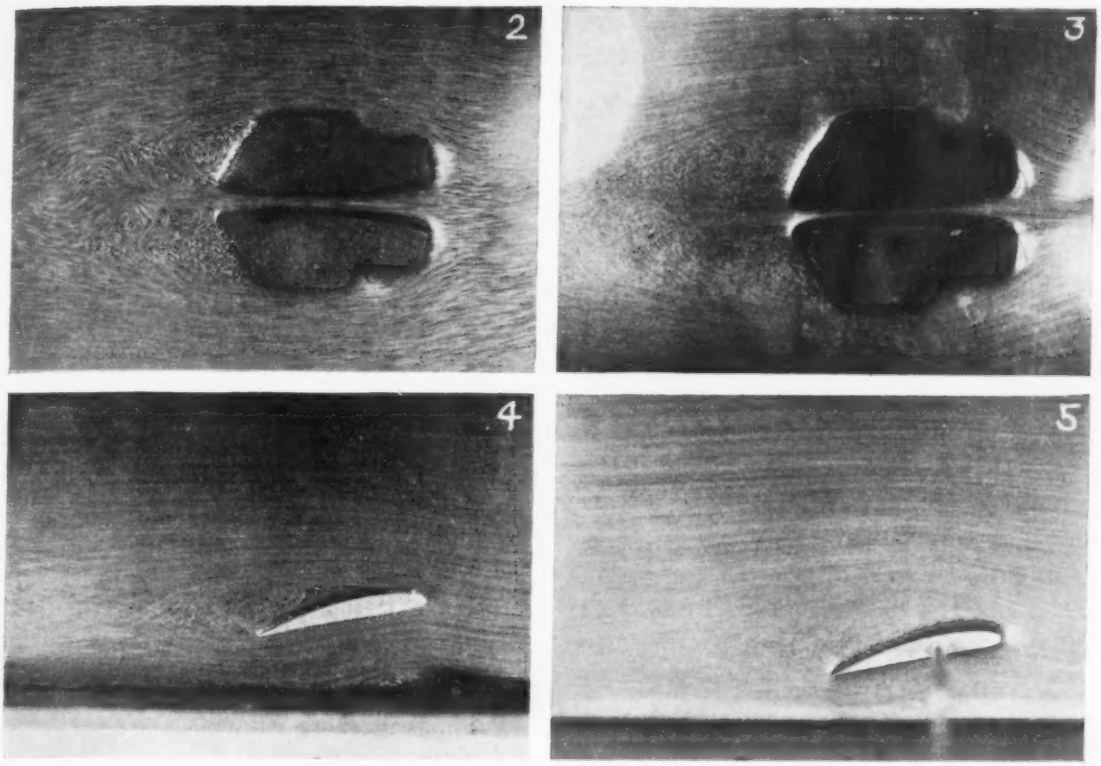
An exposure of about 1 sec. was therefore given in most cases and at least two such photographs were taken for each object to obtain a mean. These precautions were most necessary in view of our present crude apparatus.

As examples, Figs. 2 and 3 give the flow pictures obtained by short and long exposures respectively of the automobile models by the image method, while Fig. 4 is the flow around a stalled airfoil near the ground by the stationary plate method.

Separation of the boundary layer along the ground plate below the leading edge is noticeable.

From such photographs, appropriate streamlines were drawn and were compared with basic flow patterns. The latter were obtained by moving the models in still water, the model and the camera having been

[1] A. Klemin, *A Belt Method of Representing the Ground*, J. Aero. Sciences, Vol. 1, No. 4, p. 198, October, 1934.



FIGS. 2, 3, 4, and 5.

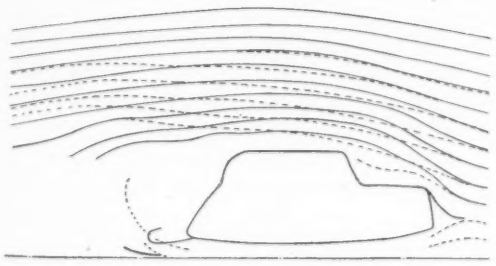


FIG. 6. Car Model. Comparison between method (1) and the moving model (full lines).

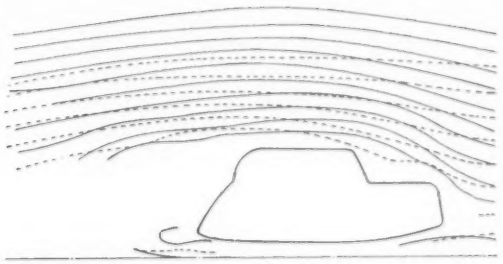


FIG. 7. Car Model. Comparison between method (3) and the moving model (full lines).

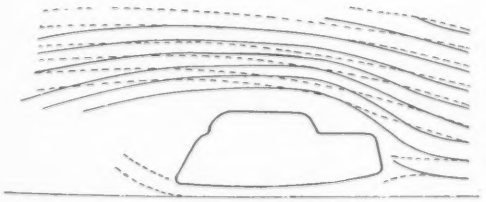


FIG. 8. Car Model. Comparison between methods (1) and (3) (full lines).

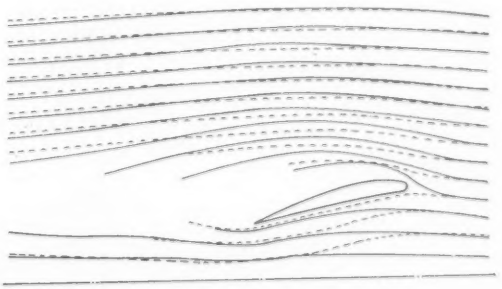


FIG. 9. Airfoil Model. Comparison between method (1) and the moving model (full lines).

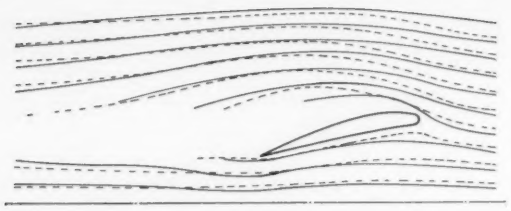


FIG. 10. Airfoil Model. Comparison between method (3) and the moving model (full lines).

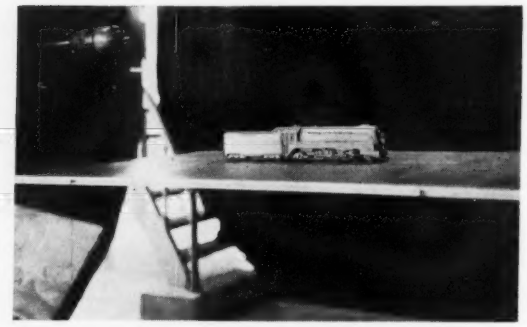


FIG. 11.

fixed to a small carriage as shown in Fig. 1. One such example is Fig. 5. The results of the comparison are given in Figs. 6–10, and can be summarized as follows:

(a) The stream lines are less curved over the stationary car model when using either method (1) or (3) than with the moving car.

(b) The above effect is more conspicuous behind the tail of the car when using the stationary plate method than when the image method is used. (Figs. 6 and 7.)

(c) Direct comparisons between methods (1) and (3) show that the former gives less flow curvature. (Fig. 8.)

(d) The flow under the car body takes a marked upward direction behind the tail in method (1). Conclusions (c) and (d) are important in showing the probable interference between the boundary layer along the ground plate and the body.

(e) Flow pictures around the stalled airfoil show quite similar tendencies, and also show the separation of the boundary layer below the leading edge in method (1) which modifies the streamline.

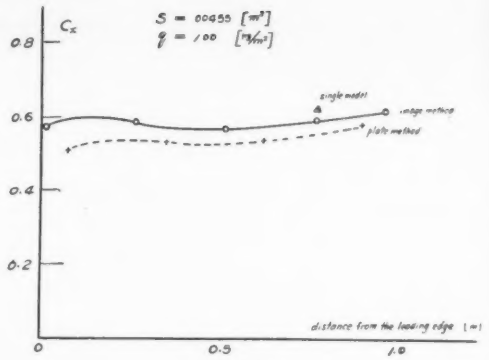


FIG. 12.

CONCLUSIONS

It may be concluded that the image model method, though not strictly ideal, gives a flow pattern more closely corresponding to the moving model than the stationary plate.

The quantitative comparison between the various methods is, up to the present, very incomplete, but some results obtained in a wind tunnel of the Kawanisi Aeroplane Works may not be out of place. They refer to the model of a locomotive as shown in Fig. 11 tested either with the stationary plate (as shown) or with an image model. The distance downstream from the mouth of the jet was varied in both cases in order to take into account the static pressure gradient effect, and the results are shown in Fig. 12, in which resistance $= c_x qS$, S being the appropriate cross sectional area of the model. The abscissa denotes the distance between the point corresponding to the leading edge of the plate and the forward end of the engine (approximately at the position of the headlight). The results are somewhat surprising in that the image method gives greater resistance than the plate method by a constant amount for all positions except very near the mouth of the jet where the difference becomes larger. At one point, about 0.75 m. behind the leading edge, a single model was tested, neither an image nor a plate being used,[2] and its drag coefficient was still higher than that of the image method. It appears that the resistance due to the underside of the carriage is affected primarily by the nature of the imaginary ground plane used.

[2] Reid used such a single model. See *S. A. E. Journal*, p. 180, May, 1935.

The Effect of Horizontal Variations in Center of Gravity Position on the Static Longitudinal Stability of Airplanes

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IN this paper the static longitudinal stability of an airplane will be considered as being defined by the slope of the curve of pitching moment, C_M, about the center of gravity, c.g., plotted against lift coefficient, C_L, or in some cases against angle of attack, α. Having given the stability of an airplane (or model) for a definite c.g. position, the problem often arises in practice to determine the effect on the stability of a change to a new c.g. position. In the present discussion we shall confine ourselves entirely to the effect of horizontal changes in c.g. position, i.e. those in which the c.g. distance above or below the mean aerodynamic chord, M.A.C., is unaltered If complete data are available for the airplane giving C_M about the original c.g. position, C_D (drag coefficient), and α as functions of C_L, then the curve of C_M vs. C_L or C_M vs. α with reference to the new c.g. position may be analytically or graphically determined by the methods of elementary mechanics. Unfortunately the calculations are somewhat tedious and lengthy so that an alternative, approximate procedure is highly desirable. What we shall call the "rotation method" provides such a simple, approximate solution to the problem. The method is based on the assumption that the resultant aerodynamic force on the airplane acts in a direction perpendicular to the M.A.C. and is numerically equal to the lift, and this assumption eliminates most of the undesirable calculations.

Let us consider the mathematics of the moment transfer. The equations for the exact transfer (1), and for the approximate "rotation" transfer (2), based on the assumption just mentioned, are:

$$C_{M_2} = C_{M_1} + rC_L + sC_D \qquad (1)$$

$$C_{M_2} = C_{M_1} + (\Delta\delta/t)\,(C_L) \qquad (2)$$

where:

C_{M_2} = Moment coefficient about new c.g.
C_{M_1} = Moment coefficient about original c.g.
t = M.A.C.
δ = Distance of c.g. behind the leading edge of the M.A.C. measured parallel to the latter
b = Distance of c.g. above or below M.A.C. "b" is taken as positive when the c.g. is below the M.A.C.
$\Delta\delta/t$ = Distance of new c.g. from old along M.A.C. expressed as a percentage of the M.A.C.* Plus values for rearward displacement and minus values for forward displacement (cf. Fig. 1)

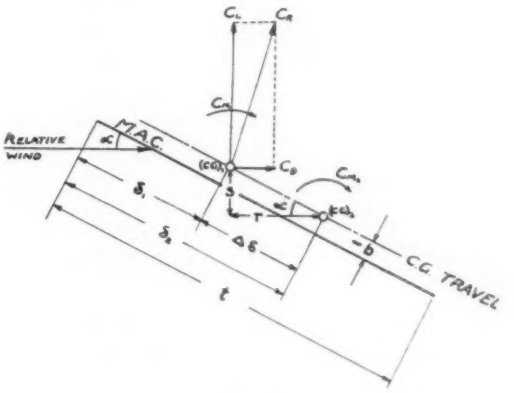

FIG. 1.

C_L = Lift coefficient from wind tunnel curves.
$r = \Delta\delta/t \cos\alpha$
$s = \Delta\delta/t \sin\alpha$
α = Angle of attack of M.A.C.

Then the error in the rotation method is:

$$\epsilon = (2) - (1) = (\Delta\delta/t)\,(C_L) - (rC_L + sC_D)$$

Due to the fact that r and s are function of α, Eq. (1) involves tedious computations but Eq. (2) provides a simple and very close approximation. With Eq. (2) we can predict the effect on the C_M vs. C_L curve for a horizontal change in the c.g. position by actually rotating the normal curve itself or, what is sometimes more convenient in practice, by revolving the C_L axis. This latter method eliminates the necessity of redrawing the curve and leads to the following procedure: At $C_L = 1$ plot a point distant from the $C_M = 0$ axis by an amount equal in magnitude to the change in c.g. position with a sign positive for a forward movement and minus for a backward movement. Through this point and the origin draw a straight line. This line is the axis from which the new moment coefficients are to be taken for a given C_L along the old C_L axis. This procedure is indicated diagrammatically in Fig. 2a.

In the case that C_M is plotted against the angle of attack, the rotation of the normal α axis is accomplished in a somewhat different manner. The angle corres-

* Notice that all distances are expressed in terms of the M.A.C. When we refer to a distance in % M.A.C. we mean numerically the percentage divided by 100, i.e. when we speak of 50% of the M.A.C. the numerical value used in the calculations is 0.5.

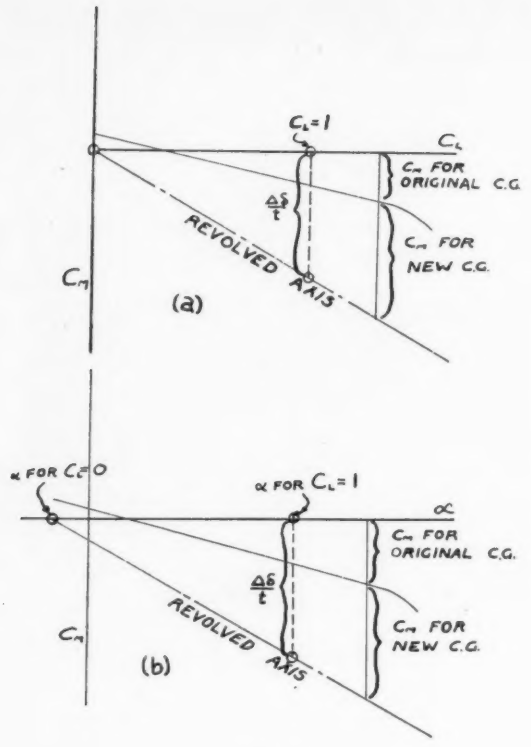

FIG. 2.

ponding to $C_L = 1$ is chosen (obtained from C_L vs. α curve of original data) and a point plotted as before. Instead of joining this with the origin, it must be joined by a straight line with a point on the $C_M = 0$ axis corresponding to $C_L = 0$. This procedure is indicated in Fig. 2b.

The approximate method has been used by designers for sometime and is by no means new. However, we do not believe its accuracy has ever been checked to provide the justification for its common use, and it was therefore the purpose of this investigation to determine from experimental data the error which might be expected in using the approximate "rotation" method.

All data were taken from reports on model tests made in the Guggenheim Aeronautics Laboratory at the California Institute of Technology. The airplanes chosen were representative of modern high speed monoplanes both commercial and military. Values were taken from the polars of C_D, α, and C_M (about c.g.) versus C_L for a zero angle of the elevator and stabilizer with the reference line, (usually the thrust axis). This last convention was chosen merely for consistency throughout. Obviously all the airplanes would not be built to fly under such conditions due to the bad trim characteristics. No values were taken from the curves above the maximum lift coefficient as these values were not considered reliable. Values above the stall would not in general agree with full scale, free air values. The limits of the center of gravity travel were chosen as ten per cent of the M.A.C. ahead and behind the normal c.g. position. This gave approximately neutral stability (C_M curve parallel to the C_L axis) for the aft c.g. position in all cases.

A general description of the airplanes used in the investigation is as follows:

"A" Parasol wing, single engine, $b/t = 50\%$, $\delta/t = 35\%$. (See Fig. 1 for notation.)

"B" High, gull-wing, single engine, $b/t = 32.15\%$, $\delta/t = 31.86\%$.

"C" Mid-wing, four engines, $b/t = 1.13\%$, $\delta/t = 25\%$.

"D" Low-wing, single engine, $b/t = 2.39\%$, $\delta/t = 16.14\%$.

"E" High-wing flying boat, two engines, $b/t = 2.85\%$, $\delta/t = 24.8\%$.
Note that although this can be classified as a high-wing with respect to the relative positions of wing and fuselage, it can also be classified as a low-wing with respect to the b/t value. The negative value is due to the elevated position of the engine nacelles above the wings.

"F" Low-wing, two engines, $b/t = -4.59\%$, $\delta/t = 33\%$.

"G" Low-wing, single engine, $b/t = 13.6\%$, $\delta/t = 37.5\%$.

"H" Low-wing, two engines, $b/t = -14.8\%$, $\delta/t = 20\%$.

To find the amount of error which may be expected in using the "rotation" method, calculations were made by the accurate method of moment transfer for the above airplanes and the results plotted versus lift coefficient. The "rotation" method was then applied and the results compared.

For rotation a slightly different method from the one previously described was used. For each C_L at which the moments were calculated points were plotted for the fore and aft "rotations" by measuring below and above the normal curve by an amount of the c.g. displacement times the lift coefficient. All moment curves were therefore plotted with respect to the same C_L axis.

Eight of the accompanying curves, Figs. 3a to 3h, show the consistency of the two methods of moment transfer. The circled points are computed by the exact formula (1) and the crossed points are obtained by "rotation," i.e. from Eq. (2). The curves were actually drawn through the computed points which were more numerous than indicated but in order to avoid confusion some of these computed points were omitted. Notice that below a C_L of 0.80 the two curves are identical for all the airplanes and that wherever there occurs a consistent difference between the two methods, the "rotation" gives the more conservative results for the aft c.g. position. By "more conservative" is meant that the slope of the approximate curve

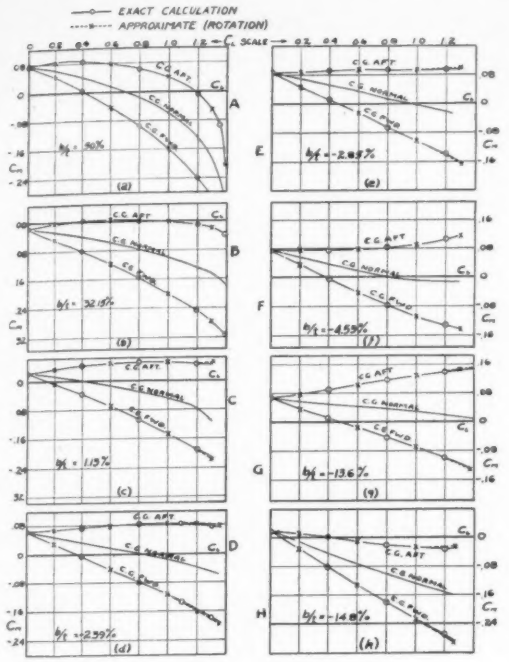

FIG. 3.

is greater than that of the exact one and hence the stability calculated approximately is less than the actual stability. The largest value for the error was .0027 which occurred at maximum lift for airplane "D". The next highest was .0017 for "H", but for the most part the errors were between zero and .0009 at maximum lift which is a difference that might well be met with when two different people carry out the computations. Furthermore, the uncertainty in the original aerodynamic data is very seldom smaller than the maximum error here obtained. We conclude, therefore, that the method of rotation of the C_M vs. C_L curve is entirely satisfactory for all practical purposes.

The results of the accurate transformation were also plotted against angle of attack to compare with the "rotation" method as applied to this case. "Rotation" was accomplished by revolving the α axis as explained above and plotting the revolved curves from this for comparison with the accurate curves.

Figs. 4a to 4c show the error encountered when the curve is "revolved." Although curves were plotted for each airplane it is sufficient to show these three as examples since the characteristics of all were the same. Notice that although the error is appreciable for the large angles, it is no more than for the C_M vs. C_L curves

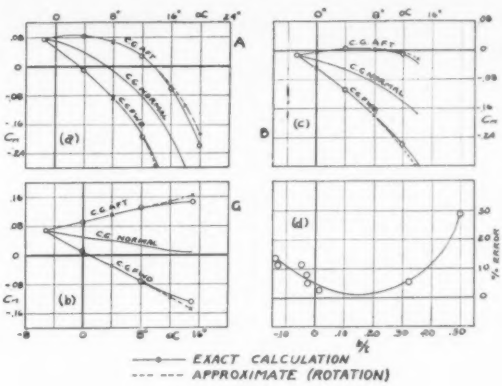

FIG. 4.

at the small angles. If we assume, as the results of this investigation have shown, that the C_M vs. C_L curve can be revolved with no appreciable error, we can readily see the reason for this. For, using this assumption, we have:

$D = (\Delta\,\delta/t)\,(C_L) =$ the difference in ordinates at any C_L between the curve for normal c.g. position and for a c.g. position displaced by $\Delta\delta/t$.

This is true whether C_M is plotted against α or C_L. If C_L is a linear function of α

$$D = (\Delta\delta/t)\,(\alpha - \alpha_0)\,(dC_L/d\alpha) \qquad (3)$$

where α_0 is the angle of attack at zero lift. Then for values of C_M below where C_L vs. α starts its curvature, it is perfectly permissible to revolve for a change in c.g. position since the expression remains linear in α. However, as soon as $dC_L/d\alpha$ becomes variable, Eq. (3) is no longer true and an error is made in the "rotation" which depends on the character of the C_L vs. α curve after its initial curvature.

It is interesting to note that for the airplanes considered in this investigation, a curve of this error as a percentage of correct D plotted versus vertical c.g. position indicates a minimum of error for a h/t of from ten to twenty percent. Such a curve is shown in the last of the figures, Fig. 4d.

In conclusion, then, we may say in general that involved computations may be avoided and accurate results obtained by the simple method of revolving the moment curve if the latter is plotted against lift coefficient. On the other hand there is no justification for applying the simplified "rotation" method to C_M vs. α curves since appreciable error may be made.

Stability of Bars with Lateral and Axial Loading

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(Received August 19, 1935)

ABSTRACT

In this paper a method of calculating critical loads is used which involves applying an auxiliary moment M at one point of the structure, calculating the resulting rotation θ, and equating to zero the derivative $dM/d\theta$. This method makes it possible to easily investigate certain modes of buckling that would otherwise be apt to escape attention, as the unsymmetrical buckling of a uniformly loaded bar of two equal spans with axial load.

The critical end load for a one or two span strut with lateral load is found to be independent of the lateral load. For a two span strut, the critical load is found to lie between the Euler loads for the long and short span separately.

Two new problems are taken up. One is that of a two-bay strut with rotationally elastic middle support. The critical load varies from the value for a simple two-bay strut when the spring constant is zero to the value for the strut with locked middle joint when the spring constant is infinite. The other new problem is that of a straight bar buckled to an arch and supporting lateral load on the convex side. The ends are held a fixed distance apart, and the problem is to find the lateral load necessary to cause collapse. It is found that $L\ q_{CR} = 23.2\ P_{eu}\ a/L$ where q_{CR} is the intensity of the critical lateral load, a the initial deflection of the buckled bar, L the length and P_{eu} the Euler load for the bar. The arched bar collapses unsymmetrically.

IN designing slender or thin walled structures it is usually necessary to give attention to the question of elastic stability. There is generally a critical value for the loading above which the structure is elastically unstable. Sometimes the critical load is such that deflections theoretically become infinite as it is approached.[1] In such cases the allowable load is determined by the allowable stress for the material. In other cases, however, the critical load may be reached before any stress exceeds a nominal value. It is therefore highly important to be sure that the proper criterion is used to determine the critical load. To have a definite knowledge of the conditions for buckling a fundamental test for stability must be applied.

The condition for the stability of a loaded elastic structure is that the total potential energy of the system shall be a minimum with respect to small deformations.[2] We are usually interested in finding the value of the critical load such that for lower loads the structure remains stable. At the critical load there is in general more than one equilibrium position, the structure being in a state of indifferent or neutral equilibrium. One way of setting up this condition for neutral equilibrium is to equate the gain in elastic energy of the structure, on passing to a new equilibrium position, to the work of the applied forces. Timoshenko[3] uses this method, and determines the buckling deformation in such a way as to make the critical load a minimum.

In this paper a method of finding the critical loading is used which was found by the author to possess some advantages for a certain class of problems. It gives the critical load value directly. The method can be applied in certain examples where the critical load is reached without the structure being in indifferent equilibrium.[4] It consists in applying a small auxiliary load to the structure, calculating the new equilibrium position, and then setting up the condition that the work done by the auxiliary load shall be zero. If the work of the auxiliary load is positive the structure is in stable equilibrium with regard to all deformations involving motion of the point of application of the load. If the work of the auxiliary load is negative the structure is in unstable equilibrium.

First of all consider the case where the auxiliary load does positive work. Let the load be ΔP, and let it be applied at the point A by means of a moving point support as shown in Fig. 1. The structure cannot be in unstable equilibrium if ΔP acts during this displacement of A, for if the structure were unstable, it would then be possible for it to have one and only one form of motion starting from rest under the action of the original loads.[5] Suppose this motion is such that the velocity of point A is $u = u(t)$. The support at A can be moved as slowly as we please, so suppose it moves with a velocity u_1 such that

$$u_1 < u$$

The structure will then move so that it loses contact with the support, and ΔP will not exist. If there is no loss of contact at A, and ΔP does work, the structure must be stable with respect to deformations involving motion of A.

Suppose now that the auxiliary load does negative work. The support at A must then be arranged to

[1] Younger, J. E., *Air Corps Information Circular*, Vol. 6, No. 581, Washington, 1926. Mr. Younger, in treating problems of the type here to be discussed, regards the critical load as that which causes the bending moment at some point to become infinite.

[2] A unified theory of elastic stability, based on the minimum energy principle was first formulated and applied by G. H. Bryan, *Proc. Cambridge Philosophical Society*, 6, 199; 1886/89.

[3] *Handbuch der Physikalischen und Technischen Mechanik*, Vol. 4, No. 1, p. 81.

[4] Example (7) discussed in this paper illustrates this point.

[5] For a proof of the uniqueness of solution of the equations of motion for an elastic body, see Trefftz, *Handbuch der Physik*, Vol. 6, p. 76.

FIG. 1.-MOVING POINT SUPPORT DOING POSITIVE WORK

FIG. 2.-MOVING POINT SUPPORT DOING NEGATIVE WORK

FIG. 3.-SIMPLE STRUT

FIG. 4.-BAR ON THREE SUPPORTS

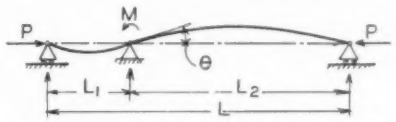

FIG. 5.-MANNER OF APPLYING AUXILLIARY MOMENT

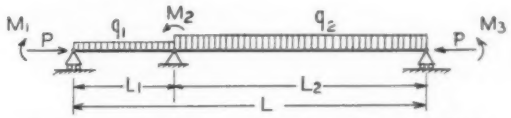

FIG. 6.-BAR ON THREE SUPPORTS WITH LATERAL LOAD

exert pressure in a direction opposite to the displacement of A as shown in Fig. 2. Removal of the support after the displacement would cause the deformation to increase, and the structure would not return to the equilibrium position. We can reason, also, that since negative work is done by ΔP, the energy of the system decreases and hence cannot be a minimum in the original position. The structure is thus unstable if ΔP does negative work.

For the structure to be stable, ΔP must act in the same direction as the displacement Δn of A regardless of how small the displacement Δn. We therefore say that if the derivative dP/dn is positive, the structure is stable with respect to all deformations involving motion of A in direction n. If dP/dn is negative the structure is unstable. If dP/dn is zero we have the condition for calculating the critical load. Care must be taken to make sure there are no deformations which do not involve displacements of the selected point A which would lead to lower critical loads.

In this paper we consider several examples in the buckling of thin bars on two or more supports. The method consists in applying an auxiliary moment, M, at one of the supports, calculating the rotation, θ, at that support, and equating to zero the derivative $dM/d\theta$. This gives an equation for calculating the critical load. If $dM/d\theta$ is positive the bar will be stable; if negative the bar will be unstable.

(1) First of all, consider a simple pin ended strut, as shown in Fig. 3. The rotation θ at the end will be, in this case,

$$\theta = (ML/EI)(1/\omega^2 - 1/\omega \tan \omega) \qquad (1)$$

in which

$$\omega = L\sqrt{P/EI}$$

For $dM/d\theta$ to be zero we have

$$0 = \omega^2 \tan \omega/(\tan \omega - \omega) \qquad (2)$$

The minimum value of ω for which this relation holds is

$$\omega = \pi;\ P_{CR} = EI\,\pi^2/L^2 = P_{eu} \qquad (3)$$

Placing $dM/d\theta = 0$ is in this case equivalent to requiring that θ is different from zero when $M = 0$.

(2) Next consider the case of a bar on three supports with axial load P, as shown in Fig. 4. The method of finding the safe end load P involves first applying the auxiliary moment M at the middle support, as in Fig. 5. Regarding the spans separately as free bodies, with end moments M_1 and M_2 respectively, we have

$$\theta = (M_1 L_1/EI)(1/\omega_1^2 - 1/\omega_1 \tan \omega_1);$$
$$\theta = (M_2 L_2/EI)(1/\omega_2^2 - 1/\omega_2 \tan \omega_2) \qquad (4)$$

By placing $M = M_1 + M_2$ we obtain

$$M = (EI\,\theta/L_1)(\omega_1^2/[1 - \omega_1 \cot \omega_1]) + (EI\,\theta/L_2)(\omega_2^2/[1 - \omega_2 \cot \omega_2]) \qquad (5)$$

from which we find

$$dM/d\,\theta = (EI/L_1)(\omega_1^2/[1 - \omega_1 \cot \omega_1]) + (EI/L_2)(\omega_2^2/[1 - \omega_2 \cot \omega_2]) \qquad (6)$$

The condition for buckling is that $dM/d\theta = 0$. If we make the substitution $\omega = L\,(P/EI)^{\frac{1}{2}}$ the right hand member of Eq. (6) vanishes when[6]

$$\left.\begin{aligned} &\omega > 0 \\ &\sin (L_1/L)\,\omega \sin (L_2/L)\,\omega - \omega\,(L_1 L_2/L^2) \sin \omega = 0 \end{aligned}\right\} \qquad (7)$$

The smallest root is a function of L_1/L. Values of ω corresponding to various L/L ratios were calculated and are given in Table I.

Table I

Critical Load for Bar on Three Supports

L_1/L	0.2	0.3	0.4	0.5	0
L_2/L	0.8	0.7	0.6	0.5	1
ω	5.18	5.63	6.06	2	4.49
P_{CR}	$2.72\ EI\pi^2/L^2$	$3.21\ EI\pi^2/L^2$	$3.72\ EI\pi^2/L^2$	$4\ EI\pi^2/L^2$	$2.04\ EI\pi^2/L^2$

[6] This result checks with that obtained by Timoshenko from the modified three moment equation. Auerbach-Hort, *Handbuch der Physikalischen und Tech. Mech.*, Vol. 4, No. 1, p. 106.

Table II

Critical Loads for Bar with Rotationally-Elastic Middle Support and Two Equal Spans

($P_{eu} = EI\pi^2/L^2$)

kL/EI	0	∞	1	2	3	5	10	20	40
$\omega/2$	π	1.43π	1.025π	1.047π	1.064π	1.10π	1.166π	1.245π	1.316π
P_{CR}	$4\,P_{eu}$	$8.18\,P_{eu}$	$4.20\,P_{eu}$	$4.39\,P_{eu}$	$4.53\,P_{eu}$	$4.83\,P_{eu}$	$5.43\,P_{eu}$	$6.20\,P_{eu}$	$6.92\,P_{eu}$

The critical load is always larger than the Euler load for the long span and less than the Euler load for the short span. Values of ω have been plotted against L_1/L in the curve shown in Fig. 13.

(3) As a third example, let the bar on three supports have transverse as well as axial loading, as shown in Fig. 6. To determine the critical load P_{CR} for this bar we apply the auxiliary moment M in addition to M_2 at the middle support. The external moment $M_2 + M$ will then be divided between the two spans, with moment M'_2 applied to the left span and M''_2 applied to the right span. Considering each span separately as a free body we can set down two expressions for the rotation θ at the middle support.

$$\theta = (q_1 L_1/P)\,([1-\cos\omega_1]/[\omega_1\sin\omega_1] - 1/2) + (M'_2 L_1/EI)\,(1/\omega_1^2 - 1/\omega_1\tan\omega_1) + (M_1 L_1/EI)\,(1/\omega_1\sin\omega_1 - 1/\omega_1^2)$$

$$\theta = (-q_2 L_2/P)\,([1-\cos\omega_2]/[\omega_2\sin\omega_2] - 1/2) + (M''_2 L_2/EI)\,(1/\omega_2^2 - 1/\omega_2\tan\omega_2) + (M_3 L_2/EI)\,(1/\omega_2^2 - 1/\omega_2\sin\omega_2) \qquad (8)$$

Now $M_2' + M_2'' = M_2 + M$, so

$$(EI/L_1)/(1/\omega_1^2 - 1/\omega_1\tan\omega_1)\{\theta - (q_1 L_1/P)\,([1-\cos\omega_1]/\omega_1\sin\omega_1 - 1/2) - (M_1 L_1/EI)(1/\omega_1\sin\omega_1 - 1/\omega_1^2)\} + (EI/L_2)/(1/\omega_2^2 - 1/\omega_2\tan\omega_2)\{\theta + (q_2 L_2/P)([1-\cos\omega_2]/\omega_2\sin\omega_2 - 1/2) + (M_3 L_2/EI)(1/\omega_2\sin\omega_2 - 1/\omega_2^2)\} = M_2 + M \qquad (9)$$

The condition for buckling is that $dM/d\theta = 0$, or

$$(\omega_1^2/L_1)/(1-\omega_1\cot\omega_1) + (\omega_2^2/L_2)/(1-\omega_2\cot\omega_2) = 0 \qquad (10)$$

This leads directly, again, to Eq. (7), the condition for buckling of the bar on three supports without transverse load. In this case, however, the angle θ generally increases without limit as the critical load is approached.

An interesting particular case is that of the bar of two equal spans, with $q_1 = q_2$, $\omega_1 = \omega_2$ and $M_1 = M_2 = M_3 = 0$. For this case $L_1/L = 0.5$ in Eq. (7), and by Table I the critical load is

$$P_{CR} = 4\,EI\,\pi^2/L^2$$

At this load the bar will be unstable with respect to deformations involving rotation at the middle support. Suppose we had used a different criterion for determining the critical load, namely, that the bending moment at the middle support becomes infinite.[1] This would lead to the value

$$P_{CR} = 8.18\,EI\,\pi^2/L^2$$

which is the critical load for a bar constrained to remain horizontal at the middle support. This emphasizes the importance of considering all possible modes of buckling when calculating the critical load.

(4) As a related problem consider the case of elastic mounting at the middle support. Let the support be rigid, however, with respect to displacements normal to the bar. The moment M_2 in Fig. 6 is applied by means of a spring, such that $M_2 = -k\theta$. If we place $M_2 = -k\theta$ in Eq. (9) and differentiate with respect to θ, we have, by placing $dM/d\theta = 0$:

$$(\omega_1^2/L_1)/1-\omega_1\cot\omega_1) + (\omega_2^2/L_2)/(1-\omega_2\cot\omega_2) + k/EI = 0 \qquad (11)$$

Suppose we have equal spans as in Fig. 8, with $\omega_1 = \omega_2 = \omega/2$ where $\omega = L\,(P/EI)^{\frac{1}{2}}$. Then the condition for buckling becomes

$$\omega^2/(1-[\omega/2]\cot\omega/2) + kL/EI = 0 \qquad (12)$$

The critical values of $\omega/2$ vary from π when $k = 0$ to 1.43π when $k = \infty$. When $k = 0$ there is no externally applied moment at the middle support, and when $k = \infty$ this moment is such as to always keep the bar horizontal. Critical values of $\omega/2$ and P are given in Table II for various values of kL/EI.

Eq. (11) not only expresses the fact that $dM/d\theta$ is zero, but also that the bar is in equilibrium with $M = 0$ and θ not equal to zero, providing q_1 q_2, M_1 and M_3 are zero. When the critical load is reached, therefore, such a bar would be in a state of indifferent equilibrium.

(5) As the next example, consider a bar with axial load and equal moments at the ends, as shown in Fig. 9. Since it often happens in the case of bars with transverse and axial loading that the critical load is reached when the expressions for the deflection and curvature become infinite one might presume that in this example the critical load will be reached when the angle θ becomes infinite. The expression for θ is

$$\theta = (M_0 L/EI)\,(1/\omega^2 - 1/\omega\tan\omega) - (M_0 L/EI) \times (1/\omega\sin\omega - 1/\omega^2) \qquad (13)$$

which becomes infinite when $\omega = 2\pi$ and not before. It is not correct to determine the critical load in this manner, because no consideration has been given to

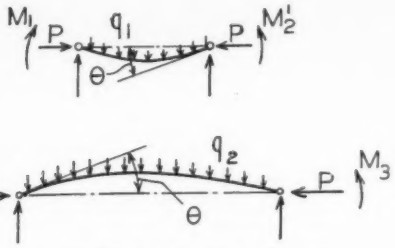

FIG. 7:-FREE BODY DIAGRAMS OF SPANS SEPARATELY

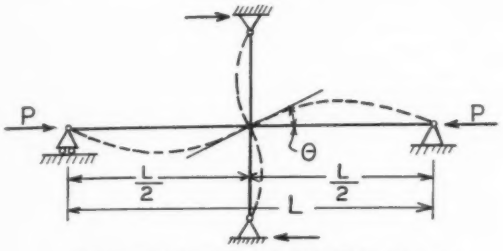

FIG.8:-BAR WITH ROTATIONALLY ELASTIC MIDDLE SUPPORT

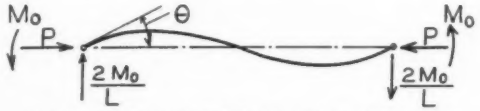

FIG.9:-BAR WITH EQUAL END MOMENTS

the stability of the bar with respect to buckling to one side or the other out of the line of symmetry. To determine the critical load for this mode of buckling we apply the auxiliary end moment M at the left support. Then θ becomes

$$\theta = [(M_0 + M)L/EI][1/\omega^2 - 1/\omega \tan \omega] - [M_0 L/EI] \times [1/\omega \sin \omega - 1/\omega^2] \quad (14)$$

Calculating the derivative $\frac{dM}{d\theta}$ and equating it to zero, we find as the condition for buckling

$$(EI\,\omega^2/L)/(1 - \omega \cot \omega) = 0 \quad (15)$$

from which $\omega = \pi$ and

$$P_{CR} = P_{eu} = EI\,\pi^2/L^2$$

(6) Suppose we have a bar on two hinge supports with axial load, end moments and non-uniform lateral load. If the loads are such that they do not change with deformations of the bar, we can write for the slope at one end

$$\theta = \theta_1 + \theta_2 + (ML/EI)\,(1/\omega^2 - 1/\omega \tan \omega)$$

where M is an auxiliary moment applied at the end, θ_1 is the rotation caused by the lateral and axial load, and θ_2 is the rotation caused by the end moments and axial load. The derivative $dM/d\theta$ then vanishes when

$$\omega^2/(1 - \omega \cot \omega) = 0 \quad (16)$$

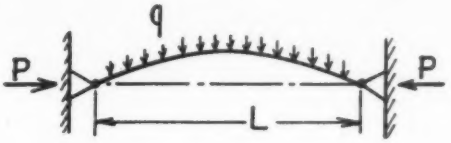

FIG.10:-LATERALLY LOADED BUCKLED BAR

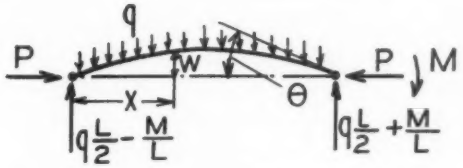

FIG.11:-EQUILIBRIUM OF LATERALLY LOADED BUCKLED BAR

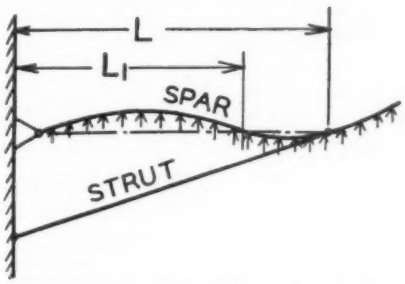

FIG.12:-WING SPAR OF EXTERNALLY BRACED MONOPLANE

from which $\omega = \pi$. The critical load for any single bay strut is therefore the Euler load $EI\pi^2/L^2$. However, if the applied forces or moments depend upon the deformation, as in example (4), in such a way that the forces arising from the deformation do negative work, the critical load will in general be above the Euler value.

(7) As the last example, we consider a bar that is buckled by end loads, and then held in the buckled position by pins at the ends a fixed distance apart, while lateral load is applied, as indicated in Fig. 10. In this case P increases with the lateral load q, and we seek the critical value of q which causes the bar to reverse its deflection and curvature.[7] We assume deflections are so small that the curvature may be replaced by d^2w/dx^2.

[7] The corresponding problem for a load concentrated at the middle of the strut instead of a distributed load was treated by A. Nadai (*Technische Blätter*, 1915, Prague). Large deflections were considered in this treatment, but the possibility of unsymmetrical buckling was ruled out. The corresponding problem for a bar with initial curvature and no initial axial load was treated by S. Timoshenko and others. Timoshenko, *Strength of Materials*, Vol. 2, p. 601, D. Van Nostrand & Co., New York.

If the auxiliary moment m is applied at the end, the equation of equilibrium for the bar as shown in Fig. 11 is:

$$EI\,(d^2w/dx^2) = (qL/2 - m/L)\,x - qx^2/2 - Pw \tag{17}$$

which, when solved, gives for the deflection curve

$$w/L = (qL^3/EI\,\omega^4)\,(1 - \{\cos\omega[x/L - 1/2]\}/\cos\omega/2) - (qL^3/2\,EI\,\omega^2)\,(x^2/L^2 - x/L) + (mL/EI\,\omega^2)$$
$$([\sin\omega\,x/L]/\sin\omega - x/L) \tag{18}$$

in which $\omega = L\,(P/EI)^{\frac{1}{2}}$

The slope, θ, at the right hand support is found to be (compare with second Eq. (8)

$$\theta = -(dw/dx)_{x=L} = (qL^3/EI)\,(1/2\,\omega^2 - [1 - \cos\omega]/\omega^3\sin\omega) + (mL/EI)\,(1/\omega^2 - 1/\omega\tan\omega) \tag{19}$$

in which we must remember ω is a function of M. To find the relation between ω and M we set up the condition that the difference between the arc length of the deflection curve and the distance between the end supports is a constant. This difference is

$$\lambda = 1/2\int_o^L (dw/dx)^2\,dx \tag{20}$$

We assume the elastic contraction PL/AE is small compared to λ and can be neglected.

By taking the derivative of w in Eq. (18) substituting in (20) and integrating we obtain for λ:

$$\lambda/L = Q^2\,U_0 + MQ\,U_1 + M^2\,U_2 \tag{21}$$

in which

$$Q = qL^3/EI;\ M = mL/EI;\ U_0 = 5/4\,\omega^6 + 1/24\,\omega^4 - (5/2\,\omega^7)\tan\omega/2 + (1/4\,\omega^6)\tan^2\omega/2$$
$$U_1 = (1/\omega^4)\{(1/2\,\omega)\tan\omega/2 - 1/4\cos^2\omega/2 - 1/2 - (\cos\omega - 1)/\omega\sin\omega\}$$
$$U_2 = (1/2\,\omega^4)\{[(\omega^2/2)/\sin^2\omega]\,[1 + \sin 2\,\omega/2\,\omega] - 1\}$$

The derivative $d\theta/dm$ is given by

$$d\theta/dm = \partial\theta/\partial m + (\partial\theta/\partial\omega)\,(d\omega/dm) \tag{22}$$

where $\partial\theta/\partial\omega$, $\partial\theta/\partial m$ can be found from Eq. (19). $d\omega/dm$ is found by differentiation of Eq. (21):

$$0 = Q^2\,(dU_0/d\omega)\,(d\omega/dM) + MQ\,(dU_1/d\omega)\,(d\omega/dM) + Q\,U_1 + M^2\,(dU_2/d\omega)\,(d\omega/dM) + 2\,M\,U_2$$

When $m = 0$ we have

$$d\omega/dM = -(U_1/Q)/(dU_0/d\omega);\ d\omega/dm = -(L\,U_1/EIQ)/(dU_0/d\omega) \tag{23}$$

Now

$$\partial\theta/\partial\omega = Q\{-2/\omega^3 + [(3\sin\omega + \omega\cos\omega)\,(1 - \cos\omega)]/[\omega^4\sin^2\omega]\} + M\{-2/\omega^3 + [\omega\sec^2\omega + \tan\omega]/[\omega^2\tan^2\omega]\} \tag{24}$$

$$\partial\theta/\partial m = (L/EI)\,(1/\omega^2 - 1/\omega\tan\omega) \tag{25}$$

Placing (23), (24) and (25) in (22), with $M = 0$ we have

$$\frac{d\theta}{dm} = \frac{L}{EI}\left\{\frac{\left(\frac{1}{\omega^2} - \frac{1}{\omega\tan\omega}\right)\frac{dU_0}{d\omega} - U_1\left(-\frac{2}{\omega^3} + \frac{3\sin\omega + \omega\cos\omega)\,(1 - \cos\omega)}{\omega^4\sin^2\omega}\right)}{\frac{dU_0}{d\omega}}\right\} \tag{26}$$

where

$$dU_0/d\omega = -30/4\,\omega^7 - 4/24\,\omega^5 - (5/2\,\omega^7)\,(1/2)\,(\sec^2\omega/2) + (35/2\,\omega^8)\tan\omega/2$$
$$+ (1/4\,\omega^6)\,(\tan\omega/2\sec^2\omega/2) - (6/4\,\omega^7)\,(\tan^2\omega/2) \tag{27}$$

We seek the least value of ω for which $d\theta/dm$ in Eq. (26) becomes infinite. We are interested only in values of ω greater than π, because ω must be greater than π for the bar to support any load q, however small. We see by inspection of (27) that $dU_0/d\omega$ is negative and not zero for values of ω between π and $2\,\pi$, and also different from zero at $\omega = 2\,\pi$. The numerator in Eq. (26) does not become infinite for $\omega > \pi$, except when $\omega = 2\,\pi$. The critical load, therefore, is the value of q which makes $\omega = 2\,\pi$. By Eq. (21), when $M = 0$

$$Q^2 = \lambda/L\,U_0$$

When $\omega = 2\,\pi$ we have

$$U_0\,(2\,\pi) = 0.00458/\pi^4;\ Q_{CR} = 14.78\,\pi^2\sqrt{\lambda/L} \tag{28}$$

If a is the initial maximum deflection before q is applied:

$$\lambda/L = (\pi^2/4)\,(a^2/L^2) \tag{29}$$

$$Q_{CR} = 7.39\,\pi^3\,a/L \tag{30}$$

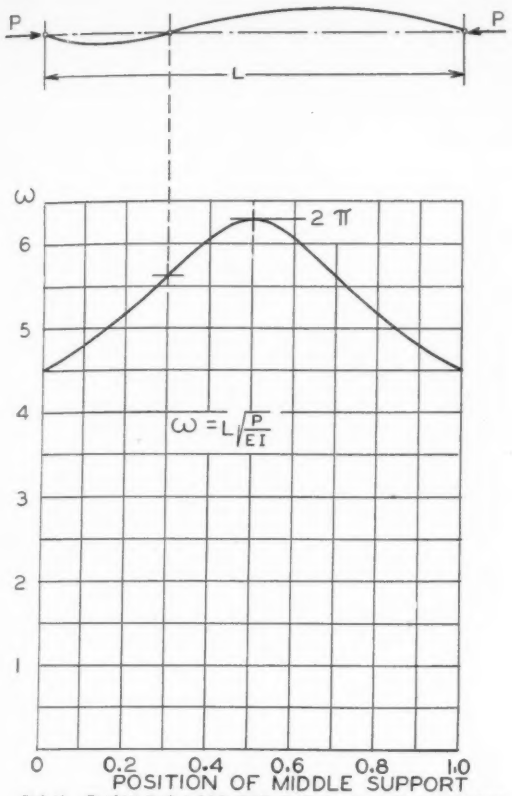

FIG.13 -BUCKLING LOAD FOR BAR ON THREE SUPPORTS

Expressing the critical lateral load in terms of the Euler load for the bar, we have

$$L\,q_{CR} = 23.2\,P_{cu}\,a/L \tag{31}$$

The corresponding axial load ($\omega = 2\pi$) is

$$(P)_{q=q_{CR}} = 4\,P_{cu} \tag{32}$$

The bar therefore buckles at the lateral load which brings the axial load to the value which would cause buckling with one nodal point in the bar as a simple strut. The bar buckles unsymmetrically.

(8) Several simple experiments[8] were performed to check the conclusions reached above. A strut was set up with hinged ends and equal end moments, so that an inflection point was produced in the middle. One might think at first that the deflection would gradually increase and theoretically become infinite as the end load $P = 4EI\pi^2/L^2$ is approached. However, in agreement with the conclusion in example (5), the bar is found to buckle to the side as P approaches the load $P_{CR} = EI\pi^2/L^2$. As the end load is increased the initial deflection due to the end moments increases, until the critical value is reached.

[8] In these tests the author worked in collaboration with Mr. Robert E. Hayes, using the facilities of the Engineering Mechanics Laboratory at the University of Michigan.

A bar of flat spring steel 0.0168 in. thick and 0.746 in. wide was given an initial curvature in the form of a full sine wave. The calculated Euler load was 0.329 lb. As axial load was applied the initial deflection gradually increased without noticeable displacement of the point of inflection. At the load very slightly below the Euler load the bar became in a state of apparently indifferent equilibrium. At higher loads it was unstable in the equilibrium position.

This again illustrates the falsity of assuming that the critical load is never reached till the expression for the deflection in the equilibrium position becomes infinite. If the latter were the case, a load $4\,P_{cu}$ could have been applied.

The case of a beam on two supports with an overhang as shown in Fig. 12 is a very common problem in aircraft design. The wing spar of an externally braced monoplane is an excellent example. The air forces produce a distributed lateral load. Due to the sloping strut bracing the wing an end load is also introduced. The load on the overhang produces a bending moment at the point of attachment of the strut, and a point of inflection in the spar. Is it then proper to compute the critical load from the Euler formula using as effective length the distance L_1, from the end to the inflection point? From the conclusion reached in example (6) it follows that the full length L must be used in computing the critical end load. Tests on a model prove conclusively that the moment due to the overhang has no helpful effect in increasing the critical load, and that the critical load is $P_{CR} = EI\pi^2/L^2$. In this case, if the moment M_0 due to the overhang is less than $2\,qL^2/\pi^2$ the spar will deflect upward to an ever increasing extent as the critical load is approached. If M_0 is greater than $2\,qL^2/\pi^2$ the spar will deflect downward to an ever increasing extent. If $M_0 = 2\,qL^2/\pi^2$ the spar will be in indifferent equilibrium when P has the critical value $EI\pi^2/L^2$. $M_0 = 2\,qL^2/\pi^2$ is the end moment we would have in a bar with a clamped end, lateral load, and $P = P_{cu} = EI\pi^2/L^2$.

A model made for testing continuous beams on three supports with lateral and axial load bore out the conclusion that the critical end load is independent of the lateral loading. The critical load for the two bay strut was found, as would be expected, to lie between the critical loads for each bay separately.

In conclusion, let it be again emphasized that all possible modes of buckling must be considered in determining the critical load for a structure. Though we have here been considering only deformations which take place in a plane, the designer of slender beam-columns should give some attention to modes of buckling involving twisting or flexure out of the plane of loading.

Notes on the Dust Storms of the Spring of 1935 with Particular Reference to Airplane Weather Observations and Air Navigation

L. T. SAMUELS, U. S. *Weather Bureau*

(Received August 4, 1935)

THE recent increase in the number of Government airplane weather observation stations making daily soundings provides upper-air data of special interest in connection with the devastating dust storms which occurred over the Plains States during the early part of 1935. In some cases the dust was so dense that flights had to be cancelled but on most occasions flights were made and the upper limit of the dust determined. In the most severe storms in which observations were made, the dust extended to an elevation of approximately 14,000 feet, but in several instances its upper limit was not reached at 18,000 feet. The average height of the top of the dust for 16 storms at Oklahoma City, in which flights were made, was 7,100 feet above ground, the maximum being 9,800 feet on April 15, and the minimum 1,500 feet on February 22. Scheduled airplane weather observations at this station were cancelled on account of thick dust on March 16, April 11, May 4 and 15. At some stations, dust was encountered between 3,000 and 6,000 feet with good visibility below and above this stratum.

Airplane observations made in dust conditions revealed, in general, lapse rates[1] approximating or exceeding the dry adiabatic rate,[2] whereas flights made at times when the dust was clearing usually showed temperature inversions or isothermal conditions between the surface and 3,000 feet. The relation between conditions favorable for thermal convection, i.e., instability, and dust storms was thus clearly indicated. This was further shown by the fact that on a number of occasions the dust storms were more intense during the daytime than at night owing to the normal rise in surface temperature during the forenoon and early afternoon and consequent daytime convection.

G. R. Parkinson of Transcontinental and Western Air, Inc., found that most of the dust storms occurred in transitional Polar Pacific (N_{PP}) or Polar Pacific (P_P) air masses. The arrival of a "cold front" of transitional Polar Continental (N_{PC}) air usually resulted in the dust clearing "as if swept with a broom." In a number of cases the dust arrived "as a solid wall" extending to a height of 14,000 feet. A good example of a severe dust storm is shown in Fig. 1. The upper

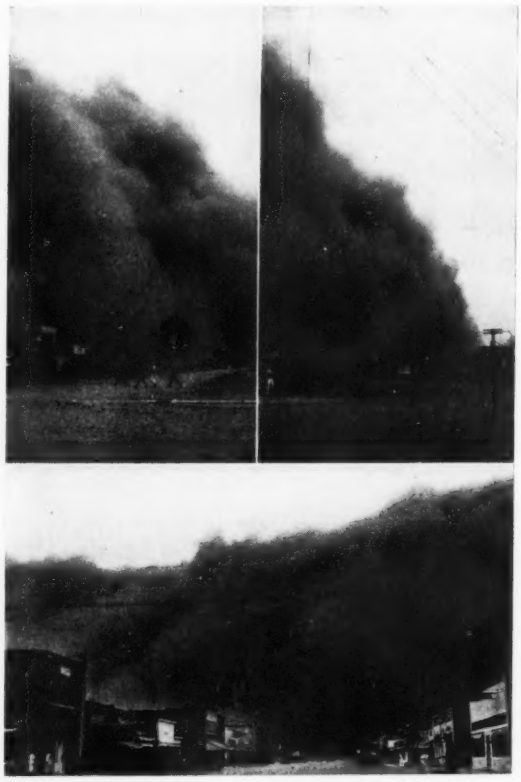

FIG. 1. Daylight to total darkness in one minute!

Photograph by R. L. Gray of dust storm at Ulysses, Kansas, at 3:10 p. m., April 14, 1935. Mr. Gray states: "Dust clouds came from the north. People told of rabbits running and birds flying ahead to escape. Rabbits and chickens were suffocated. Someone told me of their dog having pneumonia or something and about to die days afterward. They had failed to call him into the house. It was terribly dusty and it must have been absolutely dark for about a half hour. Of course it was comparatively dark but for a while even the electric lights across the street could not be seen. Persons could not detect where the windows were in the houses nor see their hands before their faces out of doors. Even the lights in the houses appeared dimmed because there usually was a lot of very fine powder dust in the air in the houses. Hardly any house could keep it out."

[1] "Lapse rate" signifies rate of decrease of temperature with height.

[2] The "dry adiabatic lapse rate" is the rate of decrease of temperature with height which a parcel of dry air would undergo if it were pushed up through the atmosphere without gaining heat from its environment or losing any thereto. The rate of decrease of temperature with height in question is approximately 1°C. per 100 meters. If the atmosphere has a lapse rate greater than this amount, a parcel of dry air when once started will rise through it due to buoyancy without an external force being necessary to push it upward, that is, the atmosphere is unstable for dry air. If the atmosphere has a lesser lapse rate, a parcel of dry air will sink back to its original level if it is pushed upward by an external force and this force then removed therefrom, that is, the atmosphere is stable for dry air.

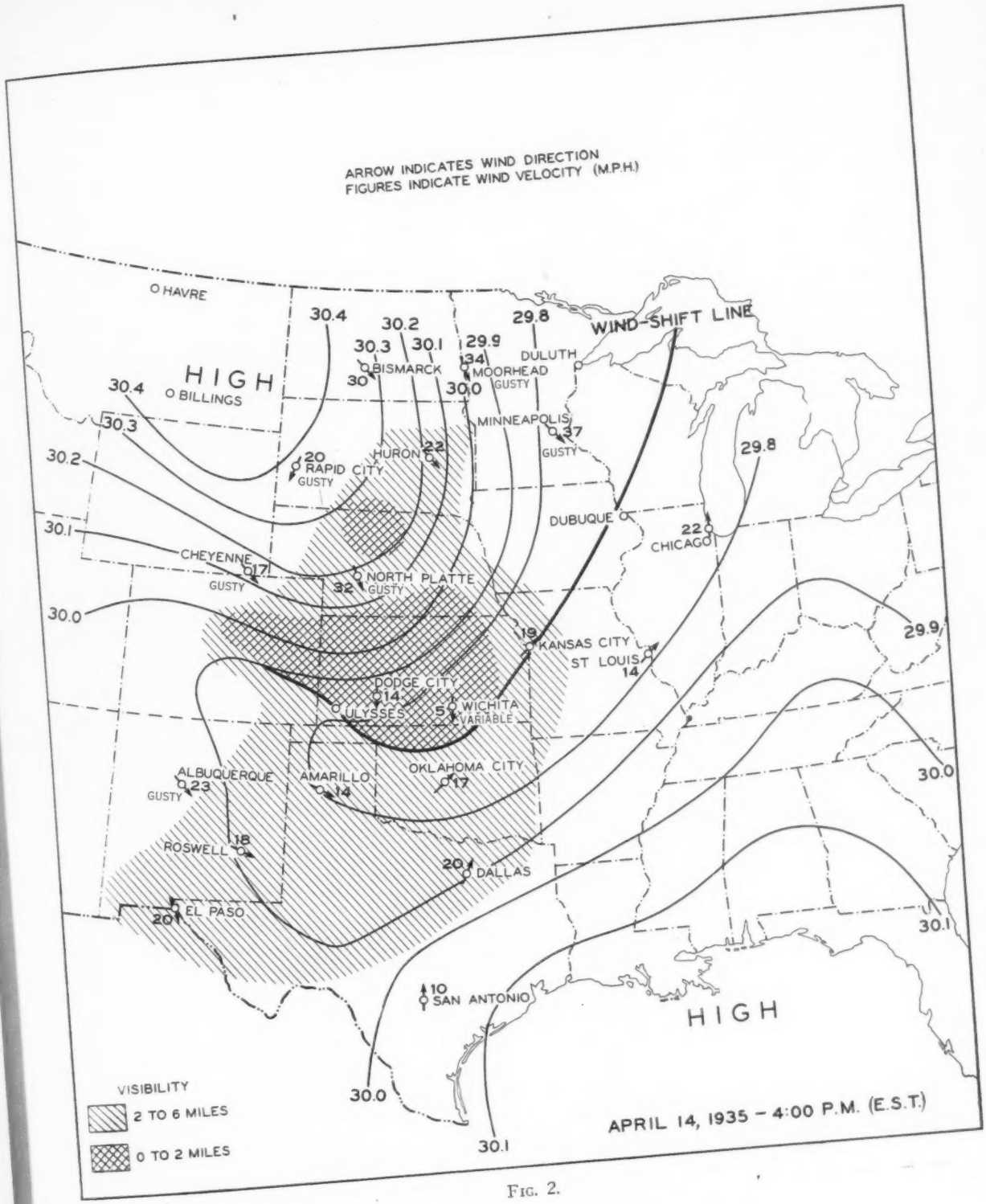
ARROW INDICATES WIND DIRECTION
FIGURES INDICATE WIND VELOCITY (M.P.H.)
HAVRE
HIGH
BILLINGS
BISMARCK
MOORHEAD
GUSTY
DULUTH
WIND-SHIFT LINE
MINNEAPOLIS
RAPID CITY
GUSTY
HURON
DUBUQUE
CHICAGO
CHEYENNE
GUSTY
NORTH PLATTE
GUSTY
KANSAS CITY
ST LOUIS
DODGE CITY
ULYSSES
WICHITA
VARIABLE
ALBUQUERQUE
GUSTY
AMARILLO
OKLAHOMA CITY
ROSWELL
DALLAS
EL PASO
SAN ANTONIO
HIGH
VISIBILITY
2 TO 6 MILES
0 TO 2 MILES
APRIL 14, 1935 – 4:00 P.M. (E.S.T.)

FIG. 2.

limits of the dust cloud as shown by airplane observations made on this and the following day are given in Table I.

TABLE I

		Feet above ground	
Date	*Station*	*Lower Limit*	*Upper Limit*
April 14	Omaha, Nebr.	1200	11,000
	Scott Field, Belleville, Ill.	ground	11,500
April 15	Omaha, Nebr.	ground	3,200
	San Antonio, Tex.	ground	13,000*
	Oklahoma City, Okla.	ground	9,800

* Maximum elevation reached by airplane.

The dust storm areas are shown in Fig. 2 together with the isobaric configurations of the 4 p.m. weather map of April 14. (Drawn by J. H. Ferguson, Weather Bureau Airport Station, Dallas, Texas.)

Three principal types of dust storms were observed by L. A. Warren, of the Weather Bureau Airport Station, Kansas City, Mo., viz., (1) those associated with well defined HIGHS to the northwest of Kansas City which seemed to carry the dust in a more or less direct southeasterly direction, in many cases reaching the Gulf of Mexico; (2) those associated with LOWS centered over eastern Nebraska or northeastern Kansas, the dust being carried from western Kansas and Nebraska; and (3) those caused by moderate to strong southwesterly surface winds, not particularly associated with any well defined pressure area, when the dust would be carried from northern Texas and Oklahoma northward to Iowa. The latter was of much shorter duration than the other two and usually less severe.

It is evident from the foregoing that the chief prerequisites for dust storms are, first, a "source region," i. e., a region to provide the dust, and second, a steep temperature lapse rate, at least in the lower levels, i. e., a condition favorable for ascending air currents. While strong winds were generally conducive to dust storms, these storms sometimes occurred with wind velocities as low as 8 to 10 miles per hour.

So far as the effects of the dust storms on air navigation are concerned, it appears that the night schedules were most affected. During daylight hours, where the terminals remained closed-in by thick dust, the shorter flights were often delayed or cancelled. However, longer flights, e. g., 700 to 800 miles, where thick dust prevailed between the terminals, were not seriously affected, since the airplanes could fly above the dust layer. In addition to the difficulties arising from poor visibility, the dust frequently entered the motors, causing damage to the pistons, cylinder walls, valves and carburetors. Physical discomfort was experienced chiefly in the eyes and respiratory organs.

The foregoing was obtained largely from reports received from Weather Bureau station officials, particularly those of A. W. Cook, of Dallas, Tex., and L. A. Warren, of Kansas City, Mo., and also that from G. R. Parkinson of Transcontinental and Western Air, Inc.

Further Investigation of the Pitot-Static Tube

KENNETH G. MERRIAM and ELLIS R. SPAULDING, *Worcester Polytechnic Institute*

(Received August 14, 1935)

THE pitot-static tube is generally regarded as being the standard instrument for measuring the velocity of high speed air. It is curious, therefore, that there have existed tubes of several designs, no two of which have performed identically; indeed, in few cases have the performance characteristics been accurately known.

Prompted by this situation, in 1933 and 1934 the authors carried out a pitot-static tube investigation and recently submitted a report to the sponsor, the National Research Council. The reader is referred to this report for information not covered in this summary.

Extensive information contained in the references listed at the end of N.A.C.A. Report No. 420 was already available. Of these references, one of the most helpful was the report of E. Ower and F. C. Johansen, entitled "The Design of Pitot-Static Tubes" (British R. & M. No. 981).

Discussion will be simplified by the use of symbols, defined as follows:

e = Error in velocity head, in per cent.
h_v = True velocity head, in inches of water.
h'_v = Measured velocity head, in inches of water.
h_d = True dynamic head, in inches of water.
h'_d = Measured dynamic head, in inches of water.
h_s = True static head, in inches of water.
h'_s = Measured static head, in inches of water.
ϵ = Error in dynamic head, in inches of water.
δ = Error in velocity head, in inches of water.
d = External diameter of head, in inches.
d_s = External diameter of stem, in inches.
x = Distance, in multiples of "d", from static openings to base of tip.
y = Distance, in multiples of "d", from static openings to axis of stem.
i = Diameter of impact opening, in inches.
s = Diameter of each static hole, in inches.
t = Shell thickness of outer tubing, in inches.
d_t = External diameter of interior tube, in inches.
α = Form of connection between stem and head.
β = Form of tip.
γ = Form and grouping of static holes.
ν = Kinematic viscosity of air.
θ = Angle of yaw, in degrees.
Y = Plane of yaw: plane containing head axis and the stream line which impinges on tip of head.
e_o = Value of "e" when $\theta = 0$.
e_θ = Value of "e" when $\theta = \theta$.
$\Delta e = e_\theta - e_o$
K = Coefficient; definition: $h_v = Kh'_v$.
C = Zero yaw coefficient, equal to K when $\theta = 0$.
C' = Yaw coefficient; definition: $CC' = K$.

For small values of e_o and Δe, it can be shown that $C = 1 - e_o/100$ and $C' = 1 - \Delta e/100$, very nearly.

It is possible to measure e_o and Δe experimentally. The significance of these coefficients lies in the fact that the error effect of any given amount of yaw is expressed by C', while the error inherent in the tube design at zero yaw is expressed by C. If the yaw is really zero, C' becomes unity.

In practical use, the amount of yaw of a pitot-static tube is generally not precisely known, and so the determination of the relation between C' and θ, for a given instrument, is a matter of some interest. A desirable condition is one in which C' varies from unity very little as θ varies considerably from zero. As to the coefficient C, a desirable condition is not necessarily that it be unity but that it be accurately known and insensitive to small changes in shape of the instrument.

Next consider the variables which control the values of these coefficients and hence the performance of a pitot-static tube. The experience of the authors, to date, leads them to believe that

$$h'_s = f_1[h_s, \nu, h_v, d, d_s, \alpha, \beta, \gamma, \theta, Y, x, y, s, t, d_t]$$

and

$$h'_d = f_2[h_v, \nu, d, \beta, i, \theta, h_s]$$

so that

$$h'_v = f_3[h_v, \nu, \alpha, \beta, \gamma, \theta, Y, x, y, d, d_s, i, s, t, d_t]$$

From the above, it follows that

$$C = f_4[h_v, \nu, \alpha, \beta, \gamma, x, y, d]$$

and

$$C' = f_5[h_v, \nu, \alpha, \beta, \gamma, \theta, Y, d, d_s, i, s, t, d_t]$$

Although the number of variables involved makes the experimental approach to the problem seem almost hopeless at first glance, certain practical considerations make it possible to arrive at reasonably fixed specifications for such variables as d, d_s, ν, α, β, and γ, thus greatly simplifying the situation.

Although incomplete, the foregoing discussion may help a little to justify the test selections, as given in the following list to obtain:

(1) The relation between h'_s and h_v for eight models commonly used pitot-static tubes, with $\theta = 0$.

(2) The relation between h'_s/h_v, ϵ/h_v, δ/h_v and θ for the models just mentioned, with θ allowed to vary from 0 to 24 degrees and h_v held at 3 inches of water.

(3) The relation between h'_s/h_v and x (also y), with h_v, β, γ, d, t, s, d_t, and h_s held constant, for two α conditions, and $\theta = 0$.

(4) The relation between ϵ/h_v and i/d for varying values of θ up to 24 degrees, with h_v, α, β, γ, d, and h_s held constant.

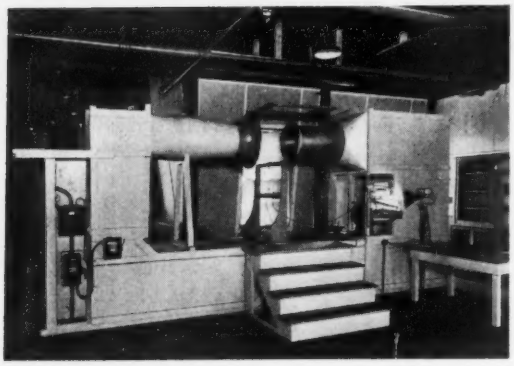

FIG. 1. Assembly of Equipment.

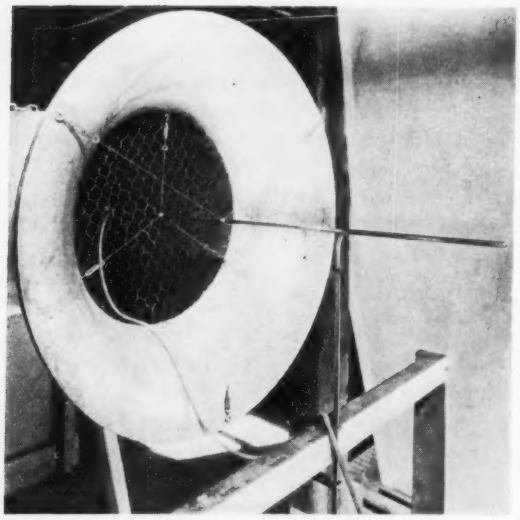

FIG. 2. Arrangement for Stern and Tip Effect Tests.

(5) The relation between h'_s/h_v and s, for values of θ between 0 and 24 degrees, with h_v, α, β, γ, d, h_s, x, y, d_t, and t held constant.

(6) The relation between h'_s/h_v and t for values of θ between 0 and 24 degrees, with h_v, α, β, γ, d, h_s, x, y, d_t, and s held constant.

(7) The relation between h'_s/h_v and d_t, for values of θ between 0 and 24 degrees, with h_v, α, β, γ, d, h_s, x, y, t, and s held constant.

(8) A considerable number of flow visualization tests, of which only one (effect of size of stem on nature of flow around head) was of general interest.

The tests in the above list were executed with the equipment shown in Fig. 1, 2, and 3. Whenever h_v was held constant, the constant value used was 3 inches of water. Pitot-static tube models were made of $\frac{5}{16}$ inch diameter brass outer tubing and $\frac{1}{8}$ inch diameter copper inner tubing. Special dummy models permitted varying x, y, t, d_t, s and i, as desired.

In the discussion of the tests, it is first necessary to admit that while the technique used is quite adequate

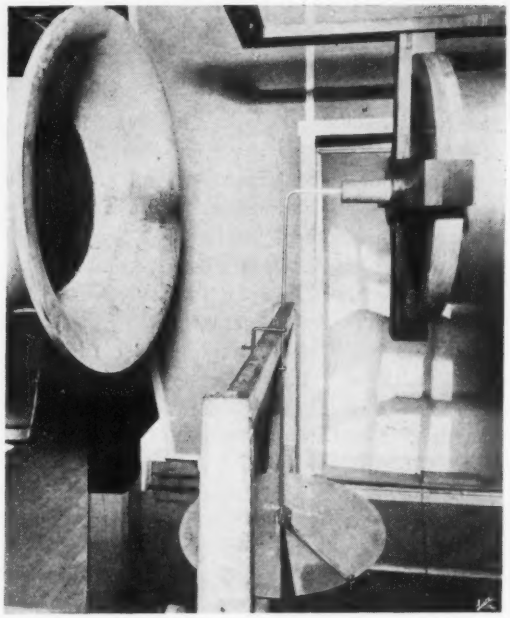

FIG. 3. Equipment and Arrangement used in Yaw Tests. Alignment Jig was Removed During Test Runs.

for obtaining *relative* magnitudes of errors in static, dynamic, and velocity heads, its accuracy in measuring *absolute* values of these errors has not been demonstrated. It is understood that the N.A.C.A. has originated a simple method of absolute calibration; if check runs are later made using this new method, the reliability of the method used in the investigation could be found. Available evidence indicates, but does not prove, that the method used should give the values of the coefficients C and C' with an absolute error of not more than $\pm$ 0.2%.

The complete picture of the controlling variables was not understood until tests (1) and (2) had been made. Special methods were evolved for measuring ϵ and δ and for correcting for slight lack of symmetry in the air stream. With a "symmetrical" instrument and air stream it is evident that the plot of, say, per cent error in velocity head ($100\ \epsilon/h_v$) versus θ should be the same whether the instrument is yawed to the right or to the left.

Tests (3) provided a satisfactory check on part of the Ower-Johansen work, previously mentioned, and it was found that application of the results of this test made it possible to explain most of the zero yaw discrepancies noted in tests (1) and (2). (At zero yaw, seven conventional models showed only about 1.5 per cent variation in velocity head error and any one of these models would give the velocity head with an error not exceeding one per cent; the eighth tube, however, which was a commercial modification of a conventional design, showed a velocity head error ranging from 14.5 to 17.5 per cent, depending on its type of application!)

Tests (4), (5), (6), and (7) dealt with variables controlling the performance of an instrument under conditions of yaw. Attention is again directed to the fact that the effective yaw of a pitot-static tube is seldom known. Mechanical alignment of a tube head with the axis of a duct, for example, does not ensure that the effective yaw is zero. Since, in practical use, an instrument will generally be acting under some effective yaw, it is important that it be as insensitive to yaw as possible.

The reader will probably be puzzled as to how s, t, and d_t can possibly affect the instrument readings. The following explanation, based on comments made by Professor Lionel S. Marks of the Harvard Engineering School, seems reasonable. When a pitot-static head is yawed, there will naturally be a pressure differential between the two sides of the head. This should tend to cause flow through the static openings from one side of the head to the other. The measured velocity head is affected by the measured static pressure head. The static pressure recorded by the manometer is the static pressure inside the pitot-static head. This pressure must surely be affected by the lateral flow through the head. The effect will depend upon the energy losses associated with this flow. The energy losses will depend upon the nature of the passage through which the air flows, and this, evidently, is determined by such items as s, t, and d_t.

A full discussion of the test results cannot be undertaken here to show how these test results suggested the design of an instrument with desirable characteristics. Careful study, however, did lead to the following specifications for a tube which tests indicate to be reliable in measuring velocity head:

(*a*) *Outer Tubing*—Brass tubing, $\frac{5}{16}$ in. diameter and shell thickness of .040 in.

(*b*) *Inner Tubing*—Copper tubing, $\frac{1}{8}$ in. diameter and shell thickness of .0285 in.

(*c*) *Shape of Tip*—Hemispherical; shape maintained by use of a simple forming tool.

(*d*) *Dynamic Opening*—$\frac{1}{16}$ in. diameter hole, drilled accurately coaxial with head.

(*e*) *Location of Static Openings*—Eight tube diameters down stream from base of tip, and sixteen tube diameters up stream from the stem axis.

(*f*) *Nature of Static Openings*—Single row of eight holes, made with a No. 60 drill (.040 in. diameter), with equal peripheral spacing in a plane normal to the head axis.

The actual performance of the instrument, when built according to these specifications, checked almost precisely with that predicted on the basis of the systematic tests. This performance can be expressed as follows:

Method of Application	*Value of C*
Without stem or extension	1.000
With stem, without extension	1.005
With stem and extension	1.010

Angle of Yaw in Degrees	*Value of C'*
0	1.000
2	.999
4	.996
6	.991
8	.988
10	.990
12	.995
14	1.005
16	1.023

As mentioned previously, available evidence indicates, but does not prove, that these coefficient values are reliable within $\pm$ 0.2%.

In the design of the instrument, it was not found feasible to attempt to cancel tip and stem effect errors at zero yaw, but otherwise the error cancellation idea could be used to good effect. Dynamic and static pressure error cancellation accounts for the remarkably small variation of C' from unity, even up to yaw angles as high as 14 degrees.

To obtain a compromise instrument which, under conditions of yaw, is not quite so accurate in recording the true velocity head but which is more accurate in recording true dynamic or total head, a $\frac{1}{8}$ in. diameter impact opening can be substituted for the specified $\frac{1}{16}$ in. diameter opening. This form of tube has been adopted as a tentative standard by the Fan Test Code Committee of the A.S.M.E. The N.A.C.A.* is now conducting research on this subject with special emphasis on the influence of variation of Reynold's number (determined by the variables h_v, ν and d).

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* As this paper was going to press the National Advisory Committee for Aeronautics informed us that the complete report of Messrs. Merriam and Spaulding, entitled "Comparative Tests of Pitot-Static Tubes," has been approved for issuance in the near future as Technical Note No. 546.
The Editor

Methods of Cabin Supercharging and Their Necessary Control Systems*

A. L. KLEIN, *California Institute of Technology*

IN considering the problem of supercharging the cabin of modern transport airplanes, many questions arise which are quite new in the field of aeronautical engineering. The writer, in this paper, will discuss some of these. The first problem to be considered will be the source of power for driving the supercharger units for securing the necessary pressure in the cabin, and next will be considered the safety precautions necessary in order to insure satisfactory commercial operation.

There are several possible arrangements of the engine supercharging for a high altitude airplane, which, for the purpose of this discussion, is defined as an airplane with an optimum altitude of from 40,000 to 50,000 feet. It is necessary to discuss the problem of supercharging the engines due to its inter-relation with the maintenance of pressure in the cabin. This discussion will be limited to 4-engine airplanes; however, these remarks will be applicable to airplanes with different numbers of engines, with obvious restrictions. There are several possible arrangements of engine supercharging systems, of which we will list a few below, namely:

(a) Sea-level engine plus external supercharger (with supercharger driven by auxiliary power plant).

(b) Engine with critical altitude of some thousands of feet plus an external supercharger (with supercharger driven by an auxiliary power plant).

(c) Engine with critical altitude plus exhaust turbo supercharger.

(d) Sea-level engine plus exhaust turbo supercharger.

Most modern aircraft engines have rotary induction systems in order to improve the distribution and, therefore, engine arrangements (a) and (d) have built into them a possible supercharger which is not used. For the altitude ranges considered in this discussion, all of the superchargers must be at least two-stage and be equipped with inter-cooling in order that the air temperatures do not reach too high values and also as the lack of inter-cooling decreases the efficiency of the supercharging very markedly.

CABIN SUPERCHARGING

The air for supercharging the cabin may be taken either from the engine supercharging system or from special superchargers driven by auxiliary power units. Let us first discuss the securing of the necessary air from the engine superchargers. This method of securing air for the cabin is possible with arrangements (a) or (d) above, but with the disadvantage that the superchargers in this system must be larger than are required with either of the other two systems. Therefore, this system is heavy. Furthermore, this system would be very difficult to control as it would either be necessary to take the cabin air from one engine, in which case the power demands on its supercharger would be larger than that of the other engines, making synchronizing of the power unit very difficult, or it would be necessary to form a supercharger manifold connecting the superchargers of all of the engines and take air from this system into the cabin. Such a system would be difficult to manage so as to prevent loss of supercharging if one engine stopped, due to backflow or leakage of air, and it would also run into great complexities in the engine control system.

Probably the best system for the class of airplanes considered would be a pair of auxiliary power units to supercharge the cabin. These same units could be used to operate the auxiliaries, which would otherwise be driven by auxiliary power plants.

GENERAL CABIN SUPERCHARGING REQUIREMENTS

The cabin pressure must be maintained at nearly sea-level value at all times, as in sleeper planes it has not been found satisfactory to permit passengers to change altitude while sleeping since they do not swallow enough to equalize the pressure in their ears, thus causing great physical discomfort. Furthermore, as has been found by Rockefeller in his studies of best flight paths for transport airplanes,[1] it is highly desirable to maintain very high rates of descent in order to make the best schedule. Rockefeller found that rates of descent up to 2,000 feet per minute would be desirable from a purely time elapsed point of view. These dive rates are much too high for passengers, so if they are desired, the cabin pressure must be maintained at practically a sea-level value.

An airplane enroute will fly from a field at one altitude to a field at another altitude, making it desirable for the pressure in the cabin to be changed so as to be nearly that of the field at both the start and the destination. The actual pressure can, of course, be that of a few hundred feet above the field at the destina-

* Presented at the Pacific Coast Meeting of the I. Ae. S. at Los Angeles, October 4, 1935.

[1] W. C. Rockefeller, *Optimum Flight Path in Air Transport Operation*, J. Ae. S., Vol. 2, No. 3, May, 1935.

tion. The rate of change of cabin pressure in order to satisfy the above mentioned conditions should be as slow as possible and, in any case, should not exceed a rate of change of pressure corresponding to a sea-level rate of climb of 100 feet per minute.

It is absolutely necessary that the sudden changes in cabin pressure, due to action of the pressure regulating system, be not more than .03 lbs./sq. in. or $\pm$ 10 feet pressure altitude at sea-level. It has been found by experiment that continual sudden changes of more than this amount cause great discomfort, while below this threshold changes are unnoticed.

Great pains must be taken to protect the cabin against all possible eventualities. These emergencies may be due to (1) sudden development of leaks in the cabin, (2) failure of the supercharging system, and (3) failures of the pressure control system.

Specific Cabin Supercharging Requirements

It is desired to design a system to supply air to the cabin with a 10 lbs./sq. in, rise in pressure in order to maintain nearly sea-level pressure in the cabin for the high altitudes considered.

It is desired to supply 5 cubic feet per minute per passenger. This supply of air is sufficient for breathing purposes but not sufficient for bodily comfort, so that it will be necessary to recirculate the cabin air in order to maintain an adequate heating and ventilating system. The power requirements per passenger for the above amount of air and pressure rise are 1 horsepower per passenger plus 100% allowance for leaks and duct losses, or 2 horsepower per man of passengers or crew. The entire system, except the ventilating ducts and recirculating fan, must be duplicated in case of failure of one unit.

Safety Measures

(1) It should be possible to arrive at a field at any desired pressure and prevent the cabin pressure from rising above the outside atmosphere pressure at low altitudes.

(2) The cabin must be sealed off instantaneously in case of supercharger failure in order to hold the pressure for the maximum length of time.

(3) In case of failure of the supercharging system, means should be provided for filling the cabin with oxygen so as to maintain consciousness of the crew and passengers.

(4) Duplicate supercharging units must be installed with provisions for rapid changeover taking not more than 10 seconds for replacing one entire supercharging system by its substitute.

(5) Windows and doors must be designed for adequate factors of safety and great precautions taken against leaks and accidental damage.

Operation of Cabin Supercharging System

Great difficulties will be experienced, as was mentioned above, in driving the superchargers from the propulsive engines, as:

(1) Engines must run at an arbitrary speed for synchronizing.

(2) Throttling control is very extravagant.

(3) Alternate supplies must be available.

(4) Precision of control is necessary and must be independent of engine operation.

Problems with auxiliary power units: at least 100% reserve capacity must be available in each unit for leakage and immediate replacement of failed unit must be made. (This means 400% capacity must be installed in the airplane.)

Devices needed and not available: practically none of the devices needed for the operation of the cabin supercharging equipment are available commercially or are under development. It will be well to list the various devices and structural needs.

(1) Window design of light weight.

(2) Door design to resist the pressure and to carry the stresses in the pressure shell across the opening.

(3) Pressure regulator of adequate sensitivity free from noise and the danger of freezing.

(4) Safety valves.

(5) Vent valves.

(6) Supercharger.

(7) Auxiliary power units of adequate capacity.

(8) Load transferring device for replacing failed unit.

(9) Emergency oxygen device.

(10) Pressure changing equipment.

(11) Check valves.

(12) Shutoff valves of light weight and adequate opening and of adequate tightness.

(13) Emergency valves for sealing off pressure cabin in case of supercharger failure.

Airplane problems: The following problems are those arising in the layout of the airplane itself and of the accessory equipment and other points that must be considered in the design of the airplane.

(1) Two power units of approximately 125 h.p. each for an airplane of 40-passengers capacity, which must be cooled in the air and soundproofed, and must be able to operate on the ground at 20% power and be equipped with a satisfactory governor.

(2) If the airplane is to be flown with or without the supercharging equipment, difficulties will be had in balancing the airplane with or without the two large power units mentioned above.

(3) The weight of the auxiliary equipment for operating the supercharging system is about 1600 lbs., of which some 400 lbs. would be carried normally in an airplane of the capacity considered in auxiliary power units whose functions would be replaced by the

larger power units necessary to supply the additional power for supercharging. In addition, the weight of the airplane would be increased in the neighborhood of 1200 lbs. by the structural reinforcements, extra heavy glass, packing glands, etc., needed for the high altitude ship. There would also be weight added to the power plants in the neighborhood of 150 lbs. per engine or, in the case considered, 600 lbs. for supercharging equipment necessary to maintain flight at the altitudes desired.

(4) Some difficulty will be found in securing adequate space for installing the supercharging equipment and its necessary controls and also adequate heating insulation and other devices needed.

(5) The cockpit design of the airplane must be as satisfactory as that in the present low altitude airplane, for in the operation of supercharged airplanes it may be found at times that it would be desirable to fly the airplane, say, westbound at low altitude and eastbound at high altitude, and in any case, the airplane must be landed and taken off.

Conclusion

The preceding discussion of the problems of the supercharged cabin airplane can be summarized in the following manner:

The devices needed, as mentioned in the section "Operation of Cabin Supercharging System", are not available commercially nor are they, to our knowledge, under development. As is well known, the design of a satisfactory automatic control system is very difficult, as troubles are always encountered with hunting and reliability. Most of the industrial automatic control systems in use at the present time are very complex and have been developed over a period of many years. It seems to the author that analogous devices will have to be developed by some engineering organization familiar with both aeronautical problems and the problems arising in industrial control systems. From information obtainable from engineers in this field, it would require at least two years of experimentation to develop a satisfactory control system to the point where it could be tried in flight, and then for a further period of one year the system would have to be operated under actual service conditions with an engineer and/or mechanic in attendance in order to insure reliability of operation under the vibrations, accelerations and atmospheric conditions met in service. It, therefore, seems to the writer that at least three years will be necessary before a safe cabin pressure system can be developed up to the point where it could be used for passenger transportation. From these considerations, it appears that one can safely say that the practical use of the supercharged transport is at least five years in the future.

Structural Features of Supercharged Cockpits and Cabins *

J. E. Lipp, *Douglas Aircraft Company*

Of the structual problems that will arise in the design of supercharged airplane cabins, the most important can be discussed by separately considering the chief component parts of the primary fuselage structure as divided into the following paragraphs.

General Arrangement

Monocoque construction is the lightest possible type of design for pressure cabins because it permits the use of a single structure for four different purposes. They are: (1) streamlining, (2) strength to support the airplane in flight, (3) resistance to the stresses caused by cabin pressure, and (4) airtightness. Other advantages and disadvantages that may exist are unimportant in comparison.

A fuselage of *circular* cross-section is necessary. Trial calculations have shown a conventional elliptic shape of 100-inch major axis and 10 pounds per square inch internal pressure ($\times$ factor of 2.5) would have bending moments in the bulkhead rings of about 250,000 to 500,000 inch pounds. The magnitude of the bending moment depends upon the distance between rings, but in any event a non-circular cross-section is definitely out of the question.

This implies that the space beneath the flooring must be kept at cabin pressure in order to prevent high bending moments in the flooring and side walls. Furthermore, particular attention must be paid to the design of the pilot's cockpit in the neighborhood of the windshields.

The cabin can be shut off from the rest of the fuselage by an airtight bulkhead (spherical in shape). Such a separator, if used, would reduce the necessary capacity of the pressure equipment to a minimum, and would simplify the problem of temperature control.

It should be a simple matter to arrange a cabin interior which will be both pleasing and conventional without violating any of the structural requirements for the general layout. In fact, the circular cross-section will give greater width, and therefore more comfort, than is to be found in a fuselage of elliptical section.

Skin Design

Vertical fuselage shear combines with longitudinal and tangential tension to give a higher shear stress in the skin of a supercharged cabin than would exist in a cabin without supercharging. It has been estimated that an increase of about 50 to 70 per cent in skin thickness must be made for this reason.

Stresses caused by bending moments in the fuselage will be discussed in the section, "Stiffeners".

An internal pressure of $10 \times 2.5 = 25$ lbs. per sq. in. will cause the skin to stretch both longitudinally and tangentially. An airplane of the size that has been mentioned above will increase about 1 inch in length and ½ inch in diameter if no restraint is placed upon the skin. This expansion is going to be a serious problem, and will be mentioned in several of the sections to follow.

It should be noticed that, although design requirements demand allowance for these large deflections, in general flight the "stretch" will be only 1/2.5 times as great and will not be noticeable to the passengers.

An annular "bulge" will occur at the bulkhead at the rear of the cabin. In the air, such an effect will be invisible to the passengers and, if no permanent deformation occurs, the "bulge" will disappear when the airplane descends to the ground.

Bulkhead Rings

The stretching of the skin, mentioned under "Skin Design", gives rise to an unusual problem in the design of bulkhead rings. Two methods of approach can be used: (1) rings can be made rigid, and (2) rings can be arranged to expand with the skin.

If the first method is used, the skin will bulge into a series of circumferential waves. This is undesirable, both from the viewpoint of strength in compression and from the viewpoint of appearance. Several other objections to this type of construction will be discussed under "Stiffeners" and "Rivets".

The second method, expanding rings, can probably be used to advantage. Rings will be lightly built and will have a special beaded attachment to the skin. Stiffener cutouts will eliminate tangential tension. Less resistance will be furnished to shear waves, changes of fuselage shape, etc., than is found in the case of rigid bulkheads. For this reason, the expanding rings, if used, will be placed rather closely together.

It seems probable that this type of fuselage construction will give rise to new methods of analysis. The ring must be considered as part of an elastic system rather than as a rigid body. The structure will permit deflections normal to the skin, but will resist tangential displacements. It may be necessary to make the skin fairly thick in order to reduce the stretching and therefore simplify the ring design.

* Presented at the Pacific Coast Meeting of the I. Ae. S. at Los Angeles, October 4, 1935.

Longitudinal Stiffeners

Stiffeners furnish a very good argument against rigid rings and in favor of the expanding rings. If the skin is not allowed to move outward at the bulkheads, the circumferential waves mentioned in the section "Bulkhead Rings" will form. This means that bending stresses will occur in the stiffeners and the allowable compressive stress will be greatly reduced. Also, the curvature will introduce eccentricity in the stiffeners and will still further destroy their efficiency as columns.

On the other hand, if expanding rings are used, the stiffeners will suffer very little bending, and will be able to develop their full strength in compression. Also, the method of attachment of the stiffeners to the rings will be simplified by the absence of bending stresses.

Compressive stresses caused by bending of the fuselage as a whole will be relieved somewhat by the longitudinal tension effect of the internal pressure. Tensile stresses will be increased by the same amount. The net effect should be no increase in weight, because stiffener design is nearly always critical in compression.

The increase of resultant shear caused by skin tension (see section on "Skin Design") may necessitate a closer spacing of stiffeners than would be the case for an unsupercharged fuselage. This will be somewhat offset by the use of smaller stiffeners to carry the compressive loads. Thus, the weight of material should not change very much with the decrease of stiffener spacing.

Rivets and Joints

In the problem of rivet design, the rigid bulkheads would again be at a disadvantage. They would cause some of the rivets to be in direct tension; a very undesirable condition because of the requirement of airtightness.

Riveted joints will require special methods of design to prevent air leaks. Two or even three rows of rivets may be necessary, in which case small rivets may be used to carry shear loads. Arrangement of joints must make it possible to have airtightness at the corners of plates where two or more joints cross each other. It may be practical to develop a technique for welding up such holes as are unavoidable.

An investigation of the waving of sheet between rivets will have to be made to the end that joints which are apparently tight on the ground will not open during flight. It is suggested that experiments be made to determine the optimum patterns for multiple row joints. Unusually large rivet heads may help in the solution of this problem, or perhaps cover straps will be useful.

Because most of the rivets will be in shear, it is to be expected that the fuselage will take a slight permanent set after having been super-charged a few times. This probably will not be great enough to affect the appearance of the airplane (in the neighborhood of the rear, airtight bulkhead). It is, however, a point that should not be overlooked.

Longitudinal and tangential tension caused by supercharging will probably increase the necessary shear area of the rivets. However, the large number of rivets required for tightness will tend to make the joints overstrength, so that no further increase of weight will be necessary.

Punched-countersunk rivets, although expensive, will be worth investigating. They are stronger than ordinary rivets, have a better appearance, and will probably help in keeping the joints tight.

Miscellaneous

A great variety of special problems will appear in the course of a design. Several of these have already come to light and will be mentioned here.

Doors must open inward and close against a frame in such a manner as to be self-sealing. Windows and doors, for the first time, must be designed as stressed members rather than as holes in the fuselage.

The floor, like the bulkhead rings, must expand with the skin. Otherwise severe stresses will be set up.

It should be possible to seal off the cockpit in case of pressure failure in the cabin. It is essential that the pilots remain conscious, and in some cases it might be to the passengers' advantage to give their share of air to the pilots. Under such an arrangement, a bulkhead of considerable weight would separate cockpit from cabin, as space limitations would not ordinarily permit this bulkhead to be made spherical.

Attachment of the fuselage to the wing must have a certain amount of flexibility to allow for expansion. This does not appear to be a particularly difficult or serious problem.

Conclusion

The chief changes in structural weight of the fuselage can be listed very simply as follows:

(a) Skin: increase 60 per cent.

(b) Bulkhead rings: uncertain, but probably not changed much.

(c) Stiffeners: no change.

(d) Rivets: increase 50 to 100 per cent.

(e) Special equipment: separating bulkheads, landing gear wells, stressed windows and doors.

The structural problems discussed in this paper are of a straightforward engineering nature and can be handled as such, even though they involve a great deal of detailed engineering. The engineering for such a project as the one considered would, of course, run into more engineering hours and therefore greater expense than the design of an equivalent low altitude airplane.

Rubber Substitutes as Coatings for Balloon Fabrics

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(Received September 6, 1935)

ABSTRACT

A brief discussion of the materials and balloon fabrics in general is included. The permeabilities to hydrogen of balloon fabrics coated with rubber substitutes and rubber-like materials are given. All have much lower permeabilities than rubberized fabric.

IN its simplest form a balloon fabric consists of a closely woven cotton cloth coated with a material which serves to render it gas-tight. In common with all structural materials employed in lighter-than-air craft, emphasis is placed upon optimum properties—strength, durability, impermeability—per unit weight of the fabric. Because of the uncommon combination of necessary qualities, many of the readily available materials which have been suggested can not be utilized successfully as coating materials. In most cases they lack the essential flexibility. A balloon fabric must withstand an unavoidably rigorous treatment involved in handling—placement in the ship, inflation, deflation—without impairment of its strength or its gas-retaining ability. The problem of providing a suitable coating consists essentially in developing a material that will withstand severe flexure under varying conditions of temperature and humidity and which will be virtually impermeable to lifting gas. Work on this problem is being conducted for the Bureau of Aeronautics, Navy Department.

It is generally recognized that the mechanism of the passage of gas through a continuous film takes place by a process of solution and not of flow through small openings. The chemical composition of the film is then a largely controlling factor in determining the rate of permeation.[2] It is unfortunate that rubber, which so adequately meets the requirements of strength and flexibility, should possess an inherently high permeability to gases. Within relatively ineffective limits the permeability of rubber is little altered by variations in compounding or curing. One of the most effective means of lowering the permeability of rubberized fabric has been the simple expedient of adding a coating of paraffin wax. By this means it is possible to lower the permeability about 60 percent, but the accompanying increase in weight may be as much as 20 percent. Furthermore a film of paraffin wax lacks continuity and permanence. To afford the high degree of impermeability desired in gas cells, it has been customary to use, either as direct coatings or to supplement rubber coatings, films of hydrophilic materials. These include such substances as goldbeaters' skin, regenerated cellulose, and gelatin. All these substances are very impermeable to hydrogen and helium. In order to maintain such substances in a flexible condition it is necessary that they be allowed to absorb a certain amount of moisture. For this purpose a hygroscopic substance such as glycerol is added. The use of a hydrophilic material presents the disadvantage that it is subject to physical changes under varying atmospheric humidities. In high humidities it may become wet, and lose strength and adhesion to the fabric, and in prolonged exposure to high humidity there is danger of loss of glycerol by leaching. In low humidities such a material may shrink and become brittle.

Other types of commonly employed coating materials, which include varnishes, cellulose derivatives, and a variety of synthetic resins, also present difficulties when applied to this problem. Aside from the fact that many of them are not particularly impermeable they do not have the desired pliability. It is customary to increase the flexibility of varnishes by including a non-drying or semi-drying oil in their composition. To cellulose derivatives and synthetic resins, liquids of low vapor pressure, referred to as plasticizers, are added. For a number of purposes such coatings are satisfactory but in attempting to apply them to balloon fabrics, the large amount of plasticizer added to obtain flexibility tends to produce excessive tackiness. Furthermore, these materials are characterized by extensibility but are not capable of corresponding retraction.

While rubber is a material which is unique in its combination of great strength and elastic extensibility, it is deficient in certain properties, which renders it unsuitable for many purposes. One of these properties is its lack of resistance to the swelling action of mineral oils. The necessity of obtaining a material which is superior to rubber in this respect has led to the development of a number of synthetic rubber-like materials. Thus the treatment of vinylacetylene with hydrogen chloride yields chloroprene, having the formula $CH_2 = C\ (Cl) - CH = CH_2$. This substance has a high rate of polymerization and yields a material whose properties more closely approach those of rubber than any material hitherto produced. An analogous material, vinyl chloride, having the formula $CH_2 = CHCl$, is capable of a high degree of polymerization and yields rubber-like gels when suitably plasticized. Both of these materials are much less permeable to

[1] Publication approved by the Director of the National Bureau of Standards of the U. S. Department of Commerce.

[2] T. P. Sager, *Permeability of Synthetic Film-Forming Materials to Hydrogen*, BS J. Research, 13, 879 (1934) RP 750.

hydrogen than is rubber. Apparently, the effect of the introduction of a halogen group in an unsaturated hydrocarbon is to reduce its permeability to hydrogen. An example of this is rubber itself. When rubber is treated with hydrogen chloride, it is possible to obtain what is known as rubber hydrochloride which differs materially from rubber but still retains some extensibility. This material has a much lower permeability to hydrogen than has rubber.

Another type of rubber-like material is that resulting from the interaction of olefin derivatives and alkaline polysulphides. These substances are presumably made up of chains which in their simplest form contain the unit $—CH_2—S—S—CH_2—$. These materials have decidedly rubber-like properties and are highly resistant to the swelling action of mineral oils.

Of still another type is the flexible alkyd resin. The flexible properties of materials of this type are interesting because they are composed of long-chain molecules resulting from the esterification of a dihydric alcohol, e.g. glycol succinate, which are attached through primary valence linkages to branched chain molecules formed by the esterification of trihydric alcohols, e.g. glyceryl phthalate. Both of these types of materials exhibit a low permeability to hydrogen.

The permeabilities to hydrogen of these materials are given in Table I. Except in the case of rubber hydrochloride the samples tested represented balloon cloth coated with the respective materials. The value for rubber represents that obtained on rubberized gas-cell fabric not coated with paraffin wax. The permeabilities are expressed as cubic feet per square yard per 24 hours and the weights as ounces per square yard. The product of the weight and permeability is included as a means of comparing the relative permeabilities. Hydrogen is usually employed in measuring the permeability of balloon fabric. In the case of rubber the permeability to helium is less than to hydrogen, the average ratio of permeabilities, helium to hydrogen, being 0.65. The value of this ratio for materials other than rubber has not been determined in every case. A few measurements made on polychloroprene and olefin polysulphide given in Table II indicate that not only is the permeability to helium of these materials less than to hydrogen but the ratios of permeabilities, helium to hydrogen, are also in close agreement with that of rubber.

The permeabilities of the rubber-like materials listed herein are all of a sufficiently low order to merit consideration. From the standpoint of balloon fabric construction, numerous factors other than relative permeability enter into the question of the suitability of a coating material. For this reason the relative utilities of the materials listed in Table I are not necessarily indicated by the relative permeabilities. Discussion of the physical properties of some of these materials will

TABLE I

Permeabilities to Hydrogen

Material	Permeability at 1 atm. ft.³/yd.²/24 hrs.	Weight of coating oz./yd.²	Permeability × weight ft.³/yd.²/24 hrs. × oz./yd.²
Rubber hydrochloride*	0.059	1.1	0.064
Olefin polysulphide	.017	3.5	.059
	.020	3.0	.060
	.023	2.9	.066
Flexible alkyd resin varnish	.026	3.6	.093
Polyvinyl chloride	.165	3.3	.544
Polychloroprene	.073†	5.7	.416
	.174	3.6	.626
Rubber	.678	2.6	1.762

* Film not supported by fabric.
† Two-ply fabric.

TABLE II

Permeabilities to Hydrogen and Helium

Material	Permeability to helium at 1 atm. ft.³/yd.²/24 hrs.	Permeability to hydrogen at 1 atm. ft.³/yd.²/24 hrs.	Ratio of permeabilities helium to hydrogen
Polychloroprene	0.047	0.073	0.64
	.106	.165	.64
Olefin polysulphide	.006	.009	.66
	.011	.017	.64
	.014	.023	.60

be found in the references given in footnotes [3, 4, 5, 6]. All of these materials have valuable application in other fields. Several of them present distinct advantages over previously developed coating materials for balloon fabrics.

Balloon fabrics coated with olefine polysulphide and polychloroprene have been prepared successfully in factory production by methods customarily employed in preparing rubberized fabric. Both materials apparently have good aging properties as determined by

[3] *Preliminary Compounding Information on Thikol B*, Bulletin IB, Thiokol Corporation, Yardville, N. J.

[4] E. R. Bridgewater, *Physical Properties of Duprene Compounds*, Ind. Eng. Chem. 26, 33, 1934.

[5] S. L. Brous and W. L. Semon, *Koroseal, a New Plastic*, Ind. Eng. Chem. 27, 667, 1935.

[6] R. H. Kienle and P. F. Schlingman, *Flexible Alkyd Resins*, Ind. Eng. Chem. 25, 971, 1933.

laboratory tests. Information in regard to service tests of envelopes and cells constructed of these materials is not yet available. The olefine polysulphide film has a remarkably low permeability per unit weight, ranking closely in this respect with many of the hydrophilic materials. This property renders it particularly attractive for gas-cell construction. While this material has rubber-like qualities its tensile strength is not as high as that of rubber. This causes difficulty in connection with seaming, it being desirable to seam balloon fabrics with cement. Among methods which have been attempted to overcome this difficulty, the use of rubber cement or combinations of rubber and olefine polysulphide appear for the present to be the most feasible.

Book Reviews

Sefton Brancker, by NORMAN MACMILLAN; William Heinemann Ltd., London, 1935; 491 pages, 21s.

When Sir Sefton Brancker was elected President of the Royal Aeronautical Society, it was generally recognized that although he was not an aeronautical engineer or scientist he had made so many valuable contributions to aeronautics that the choice was a fitting recognition of his many services to early aviation.

Captain Norman Macmillan, who compiled his biography with the assistance of friends of General Brancker in all parts of the world, has not only related the outstanding achievements of one of the founders of the Royal Air Force and a pioneer in commercial air transport but has provided a volume of historical importance which will always be an essential book of reference on the beginnings of aerial warfare.

The book divides itself naturally into two parts, as did General Brancker's career. The first part, fortunately for future students of the beginnings of aeronautical development in England, was almost entirely written by himself. It provides a documented history of how the British muddled through their aeronautical activities during the war.

His letters to General Trenchard, who later was to become the real founder of the Royal Air Force, show the invaluable role he played in making the separation from the Army and Navy inevitable. As Director of Military Aeronautics throughout the war period his papers, which deal with the problem of training, equipment and organization, are source material of the greatest value. No one will read them without recognizing the great contribution of this old time Gunner to the development of military aeronautics. His throwing red tape aside and his courage in voicing his opinions to the political and military chiefs showed a devotion to his chosen vocation far above any call of duty.

After the war Sir Sefton, who was convinced that commercial air transport was imminent in its practical development, resigned from the R. A F. and became one of the leading proponents in the world for commercial aviation. He was appointed Director of Civil Aviation in England. From that time he was continually traveling to all parts of the world, exhorting, whenever the opportunity offered, everyone he met to a greater appreciation of the future of aircraft in commerce. The book contains several of his addresses which are typical of his fluent style.

During his many visits to the United States he made countless friends who will read in this book much of his career about which they knew little. His spirit was so effervescent that it was seldom that he could be persuaded to relate bygone happenings. He was essentially a forward looking enthusiast in everything he undertook. While in the United States he did much to stimulate a lagging interest in the commercial operation of air routes. He was asked to speak before many influential groups. His gift of adapting his speeches to the particular type of audience, his wit and fund of appropos stories, his phenomenal flying experiences, as well as the distinguished position he occupied in England, all had a most beneficial influence on the incipient air transport enterprises of the time (1926).

His loss in the R. 101 was felt as keenly by his many friends in the United States as in England. He was one of those irreplaceable figures in aviation. To those who knew him well and enjoyed his friendship, the sudden termination of a career so full of future usefulness has left vacant a place which no one can ever occupy.

Air Vice Marshall Sir Sefton Brancker will occupy a prominent niche in the history of aviation. The preparation of the material in this book at a time when original sources are available is a distinct service to present and future historians.

The proceeds of the book are to be devoted to the foundation of a Sefton Brancker Memorial Fund for disabled pilots and the widows and orphans of members of the Guild of Air Pilots and Air Navigators which he founded.

LESTER D. GARDNER

Test Pilot, by JIMMY COLLINS; Doubleday Doran & Company, New York, 1935; 178 pages, $1.25.

Jimmy Collins book, *Test Pilot,* while not a technical book in any sense of the word, gives a very vivid picture of the life and experiences of one of our best test pilots. The chapter "Return to Earth" is the only one which is at all technical and has anything to do with the type of testing that Jimmy specialized in.

He was deeply interested in testing airplanes and had one of those minds that was always curious as to why things worked and he did not dive airplanes just to see if he could get away with it as Colonel Paterson suggests in his foreword.

We had many talks with regard to whether or not he should put the propeller in high pitch, thereby putting quite a strain on the motor mount by holding the engine revolutions down in the dive, or whether he should leave it in low pitch and in this way take a chance on the engine bursting by turning up too fast, also, whether it was better to set the stabilizer all the way nose heavy and have quite a pull on the stick in coming out of the dive or to set it so that the ship wanted to come out by itself and had to be held in.

When one considers that these terminal dives only last about thirty seconds and the pilot is supposed to record the air speed at the entry of the dive, the rate of increase in speed, the speed at the pull out, the stick force and direction for keeping the ship in a zero left dive, the stick force required for the pull out, the tail setting both at entering the dive and pulling out, the altitude lost in the pull out, also the amount of *G* registered in the pull out, together with looking over the whole airplane both in the dive and the pull out, one begins to realize that it is quite a task and all the more so when one has once had an airplane break under these conditions and has the deadly fear of having it happen again.

It can at least be said that Jimmy Collins did not die in vain, as the Navy has reduced the *G* required in the pull out from nine to eight directly as a result of his death. No other country or service in the world requires even this much. The

Navy believes that the ships are left out in the open most of their career and that they should be through these tests in order to stand the normal pull outs used in the service, which is seldom over three *G*, even if they may be somewhat deteriorated by age.

JAMES B. TAYLOR, JR.

Aerodynamic Theory, DR. WILLIAM FREDERICK DURAND, EDITOR-IN-CHIEF; Vol. IV, A. Betz, C. Wieselsberger, H. Glauert and C. Koning; Julius Springer, Berlin, 1935; 430 pages.

It is indeed unfortunate that the contents of each volume of such a contribution to aerodynamic theory must be treated so briefly. It is only by actual contact with the volumes themselves that one can fully appreciate the valuable material contained in them.

In the first division of the present volume, Professor A. Betz, one of the ablest of those who have been consistently tying up the loose ends existing between theory and experiment, offers a discussion of applied airfoil theory. This is divided into four sections which include the general properties of the airfoil, the properties of typical profiles, wings of finite span, and non-steady types of motion.

The subject matter, it is noted, includes many items of interest which have hitherto been available only in scientific journals, such as the effect of drag on deviations from theoretical lift values, suction control of the boundary layer, and similar topics. The encyclopedic nature of the entire work is again evidenced by this fact which increases its value accordingly. These unexpected additions to the general treatment of wing properties are refreshing.

The second section of Betz's discussion deals with flat and curved thin plates and then advances to profiles of general form and the results of experimental observations on airfoils.

Part three sets forth the general phenomena connected with the monoplane and the effect of several variables on its performance. Later, combinations of wings, including the biplane and wings in tandem arrangement and their mutual effects upon each other, are described. Unsymmetrical and non-steady types of motion are examined. Influences of sweep-back and dihedral in side slip constitute an interesting treatment. Lastly, phenomena associated with the spinning of airplanes are investigated in a very complete and satisfactory manner.

The drag of the non-lifting system of an airplane and its influence on the lift is set forth by Professor C. Wieselsberger in the second division of this volume. This discusses the effect on the aerodynamic efficiency of the various structural parts of the conventional airplane and their effect upon performance. The drags of the ideal and of the actual fuselage are compared and a treatment on scale effect is included. A generous number of important diagrams and graphs taken from experimental data are shown and will prove particularly valuable especially in the event one is seeking specific values. A theoretical development for the effect of the fuselage and engine nacelles on the wings is offered and experimental results are given for the same.

The late Mr. H. Glauert has set forth, in the third division of this work, what is probably one of the best discussions of airplane propellers. The treatment is primarily theoretical, but numerous instances occur where the practical application of the theory is stressed. The first four chapters constitute a general introduction to propeller theory and then proceed with the development of the Rankine-Froude axial momentum theory, followed by the generalized momentum theory and the discussion of propeller efficiency.

Next, the blade element theory, as developed by Drzewiecki, is presented along with an interesting portrayal of the effect of arrangements of airfoils in cascade. Then the author goes into the development of the vortex theory of propellers and derives an approximate method of solution. The effect of solidity, namely, the ratio of blade area to disc area, and pitch are dwelt upon.

Chapter seven considers the efficiencies of lightly loaded propellers, the effect of profile drag and number of blades, and the following chapter investigates propeller-body and propeller-wing interference, and gives an analysis of apparent thrust and drag. Next, the experimental study of propellers is outlined with particular attention to experimental methods, wind tunnel interference, and scale and compressibility effects.

Chapters ten and eleven deal with helicopter propellers and with windmills and fans, respectively. The final chapter deals with special propeller problems of unusual interest, namely, tandem propellers, stalled blades, the vortex ring state, the effect of sideslip and pitching, and the downwash behind a propeller.

It is indeed regrettable that one whose brilliance is evidenced by this sound treatise on aerodynamics should have met an untimely death. This and his many other writings are of a quality that merits permanence.

The final division of the present volume follows closely on the proceding divisions in dealing with the influences of the propeller on other parts of the airplane structure. C. Koning proceeds to develop the theoretical aspects of the problem by first considering the flow about the ideal propeller in the absence of other bodies and the effect of certain simplifying assumptions regarding the steadiness of the flow. He then continues the theoretical discussion by concentrating on the influence of the propeller upon the wing system which he accomplishes by the method of images, by which he compensates the flow to produce the correct slipstream boundary conditions. The equations for the change in circulation of the wing are then evoked and thence the effect upon the characteristics of the airfoil or wing section.

Chapter two deals with the applications of the theory to various problems first dealing with the finite wing in various positions relative to the propeller and then with the infinite wing across the slipstream boundary. Numerical results are given and a comparison is made with experimental data. Finally, the influence of the propeller upon the tail surfaces is investigated, and the effect upon stability and controllability. The division is an unusual and important addition to the work.

The volume contains a great number of references in the very complete bibliographies following the various divisions.

R. P. Harrington.

Institute Notes

The Fourth Annual Meeting of The Institute

The next annual meeting of the Institute of the Aeronautical Sciences will be held at the Physics Building, Columbia University, New York City, on Wednesday, Thursday and Friday, January 29th–31st.

The Meetings Committee, which is in charge of planning the sessions, wished to provide more time for discussion, and therefore urged the extension of the meeting to three days instead of the two days that were given at the Third Annual Meeting. An enlarged program is planned for this meeting, and the Council has decided to devote the third day to Air Transport exclusively.

On Wednesday, January 29th, at 5 p. m., the stated Annual Meeting of the Institute will be held. Reports of Officers will be made and the election of new members of the Council will be held.

On Thursday, January 30th, the Annual Dinner will be held at the Faculty Club of Columbia University. At that time the *Sylvanus Albert Reed Award* will be presented.

Aeronautical Exhibition

During the three days of the meeting, an exhibition of new aeronautical instruments, apparatus, accessories, etc., will be held in the Physics Building. Manufacturers of such aeronautical materials are cordially invited to participate. Further details as to space available, electrical facilities, etc., will be sent to all those wishing to participate. Please write the Secretary, Institute of the Aeronautical Sciences, 5431 RCA Building, Rockefeller Center, New York City, for any information that may be desired.

Student Branches

About two hundred Student Members from various universities and institutes have joined the Institute. Some have formed Student Branches of the Institute. Organization meetings have been held and Student Branches formed at the University of Detroit, Carnegie Institute of Technology, University of Minnesota, and University of Cincinnati.

The University of Cincinnati Branch, organized under the guidance of Professor Bradley Jones, sends the following report:

The By-Laws as proposed by Section II members of the Student Branch were adopted with minor modifications and additions. Final adoption will be carried through on November 9, 1935. A public meeting (non-technical) of the Student Branch was held on October 9, 1935. Guest speaker Commander Connell, U.S.N., discussed the flight of the Navy from San Francisco to Honolulu in 1925. His talk served to acquaint the general public with the technicalities of preparation for such a flight and also pointed out that such flights are purely scientific and are not undertaken for spectacular adventurism. A technical meeting of the Branch was held on October 19th.

Gift of a Weston Exposure Meter

So many visitors from abroad and members from various parts of the United States visit New York and take photographs that the Weston Electrical Instrument Company has presented to the Institute for their use a Weston Universal Exposure Meter.

It will also be useful in the editorial work of the Journal. Members wishing to use this meter may borrow it at the Skyport. The Institute appreciates the gift.

Distinguished Greeting to Members

A post card was received from several distinguished members of the Institute who were guests at the Volta Congress held in Rome in October. It would probably be difficult to gather at any time and in any one place a group whose names are better known for work in the aeronautical sciences. Starting with the first column and reading down the signers were: Dr. Ludwig Prandtl, Honorary Fellow of the Institute and Director of the Kaiser Wilhelm Institute for Fluid Motion Research; Dr. Th. von Karman, Director of the Daniel Guggenheim Graduate School of Aeronautics of the California Institute of Technology; Dr. Enrico Pistolesi, Professor of Applied Mechanics at the Royal Institute of Engineering in Pisa, Italy; Dr. J. M. Burgers, Professor of Aerodynamics at the Delft Technische Hoogeschool, Holland; Dr. Carl Wieselsberger, Professor and Director of the Aachen Aerodynamisches Institute, Germany; Dr. J. Ackeret, Professor of Aerodynamics at the Zurich Technische Hochschule, Switzerland; Dr. Albert Toussaint, Professor at the Institute Aeronautique, St. Cyr l'Ecole, France; and Dr. G. A. Crocco, President of the Aeronautical Section of the National Council of Research and Professor of Aeronautics at the University of Rome, Italy.

Necrology

Thomas Carroll VanStone, Engineering Member of the Institute, died on September 18, 1935. He was born October 2, 1903, in Denver, Colorado. He graduated from Harvard University in 1926 with the degree of B.S. in Mechanical Engineering. He was an engineer and test pilot with the Airplane Development Corporation of Glendale, California.

Captain Giovanni Marini of Milan, Italy, an Industrial Member of the Institute, died September 15, 1935. Born in Trieste on May 21, 1889, he attended the Superior Academy of Nautical Studies in that city and later served as a pilot-instructor in the Italian naval air service. When the airline Avio Linee Italiene was formed in 1928, he became its general manager and held that position until the time of his death. He specialized in the development of airways over the Alps.

Sylvanus Albert Reed, 1854–1935

Dr. S. A. Reed, a Fellow of the Institute, died on October 1 at his home in New York City. He bequeathed to the Institute ten thousand dollars to endow the "Sylvanus Albert Reed Award," which was established in 1934.

At a meeting of the Council the following Resolution was adopted:

Whereas, the Institute of the Aeronautical Sciences having lost by the death of Dr. Sylvanus Albert Reed not only its first Honorary Member and a distinguished Fellow but also the first of its members to provide an award with a substantial endowment, the Council of the Institute desires to express the sorrow of each member who knew Dr. Reed personally and valued his high character and scientific attainments, and wishes to record formally the regard of the entire membership of the Institute; be it, therefore,

RESOLVED; that the Institute of the Aeronautical Sciences was signally honored by the gift of the Sylvanus Albert Reed Award to be presented annually "for a notable contribution to the aeronautical sciences resulting from experimental or theoretical investigations, the beneficial influence of which on the development of practical aeronautics is apparent;" be it further

RESOLVED; that the Institute, in accepting this gift and giving it the name of Dr. Reed without suggestion from him, added to the distinction of this Award by such designation, owing to the eminent services to aeronautics which were made by the donor; be it further

RESOLVED; that the Institute perpetuate the memory of Dr. Reed by a ceremony in connection with the presentation of the Award each year at its Annual Meeting; and be it further

RESOLVED; that a copy of this Resolution be sent to the family of Dr. Reed.

The terms of Dr. Reed's will making the bequest follow:

"I give and bequeath to THE INSTITUTE OF THE AERONAUTICAL SCIENCES, INC., a membership corporation incorporated under the laws of the State of New York, the sum of Ten Thousand Dollars ($10,000), to invest the same in bonds or other obligations of the Government of the United States of America to collect and receive the income therefrom and to pay and apply the net income for the advancement of aeronautical science as follows: to give a cash award of the sum of Two Hundred and Fifty Dollars ($250), to be known as the "SYLVANUS ALBERT REED AWARD," and a certificate to be known as the "SYLVANUS ALBERT REED AWARD," at periodical intervals to be determined by said Institute of the Aeronautical Sciences, Inc., preferably annually, to a person who shall be selected as the recipient of the "Sylvanus Albert Reed Award." The rules and regulations for the selection of a recipient of said award are as follows: The recipient must be selected by the Fellows of The Institute of the Aeronautical Sciences, Inc., as being, in the opinion of the majority of them, the most distinguished in aeronautics during the previous year or years.

"It is my request that the said fund, so bequeathed to said The Institute of the Aeronautical Sciences, Inc., be administered with the advice of a committee of three persons, to wit, CHARLES L. LAWRENCE, now of No. 151 East 63rd Street, Borough of Manhattan, City of New York, LESTER D. GARDNER, now of No. 251 West 101st Street, Borough of Manhattan, City of New York and JEROME C. HUNSAKER, now of the Massachusetts Institute of Technology, Cambridge, Massachusetts, and I further direct that whenever the number of members of said committee shall be reduced by death, resignation or refusal to act below the number of three, that another member of said committee, who shall be a Fellow of The Institute of the Aeronautical Sciences, Inc., shall be chosen by a majority vote of the Fellows of said Institute to the end that there shall always be three members of such committee.

"If for any reason said gift of Ten Thousand Dollars ($10,000) made under the above conditions shall be declared invalid by a Court of competent jurisdiction, then and in that event I give and bequeath said sum of Ten Thousand Dollars ($10,000) to said THE INSTITUTE OF THE AERONAUTICAL SCIENCES, INC., absolutely, with the request that said fund be administered by it as above set forth."

Dr. Reed was born at Albany, April 8, 1854. He was the son of Rev. Sylvanus Reed and Caroline Gallup Reed. His father later was Rector of old St. George's Episcopal Church in New York for some years. He was descended from Captain Sylvanus Reed who fought at Bunker Hill on the staff of Colonel Sullivan of Newport and thereafter during the entire Revolu-

tion. When the designation of the name for the award was proposed Dr. Reed agreed as he felt that he was perpetuating the name of his ancestor rather than himself. As a descendent of this staff officer of the Revolution Dr. Reed was an hereditary member of the Order of the Cincinnati.

Dr. Reed's early training was obtained at Albany Academy and at several New York schools. He later received five degrees from Columbia University—A.B. in 1874, A.M. and E.M. in 1877, Ph.D. in 1879, and D.Sc. in 1929. The last degree was conferred on him in recognition of his aeronautical inventions. He also studied for several years at the University of Wurzburg and at the University of Berlin.

After serving as secretary to Dr. Horace Barnard, head of the American section of the Paris Exposition in 1878, he engaged in mining engineering in the West for seven years. Then followed executive positions with a number of important insurance companies, including the National Board of Fire Underwriters, the Fire Insurance Tariff Association, and the Suburban Fire Insurance Exchange, all of New York.

Dr. Reed became interested in aviation in 1911 when he and Greely S. Curtiss purchased and brought to this country the first Bleriot to be purchased by Americans.

In 1915, Dr. Reed became interested in constructing propellers made of metal. Working with duraluminum he made many types. He employed the facilities of the Curtiss Aeroplane and Motor Company at Garden City, L. I., to develop his inventions. After much research the first propeller was tested on an airplane at Curtiss Field August 30, 1921, by Casey Jones, who was then test pilot for the Curtiss company. The results of these tests were so satisfactory that plans were made for extensive development and manufacture of this new type of propeller. Official military recognition first came in 1923 when the Navy-Curtiss racers which won first and second places in the Pulitzer Trophy Race of that year were equipped with duraluminum propellers made by Dr. Reed. The two Navy-Curtiss Seaplane racers that took first and second places in the Jacques Schneider Trophy Race in England that same year also used Dr. Reed's propellers. Since these early demonstrations propellers which used the basic Reed patents have been used in almost every speed race and record performance. The rights to manufacture this type of propeller were sold to England, Japan, France, Italy and Germany.

In 1925 Dr. Reed was awarded the Collier Trophy for his propeller work. The citation accompanying the award read that it was for the "greatest invention in Aviation in America, the value of which has been demonstrated by actual use."

Dr. Reed belonged to the New York Naval Battalion from 1890 to 1892. He was a member of the Union and University Clubs and Delta Psi.

He married Miss Ella Wilshire Pomeroy of Boston. She died in 1897. His immediate survivors are two sisters, Mme. Geraldine Millet, widow of Francois Millet, son of the French painter, and Mrs. William Barclay Parsons of New York, and a brother, Latham Gallup Reed, retired New York attorney.

Late in the fall of 1934 Dr. Reed and the Secretary of the Institute were discussing the future of the Institute. Dr. Reed had shown great interest in the establishment of a scientific and engineering society devoted to aeronautics in this country and became one of the Founder members of the Institute. The question of a new award for achievements in aeronautics was considered and without hesitation Dr. Reed said he would establish it and asked that suggestions be secured as to how it would render the greatest service. So that all the problems involved in the creation of such an important endowment would be a matter of written record letters were exchanged which give clearly the actuating motives of Dr. Reed and his wishes. These have been adhered to closely but so certain was he that changes in plans and procedure would have to be made that he left the future determination of the procedure to the direction of two-thirds of the Fellows of the Institute who "shall make any changes they wish in the terms of the award, but this shall not apply to investments." This procedure was characteristic of Dr. Reed. He wanted the endowment to stimulate aeronautical research, invention and development but having known of other awards that outgrew their usefulness he left to the Fellows of the Institute the obligation of administering this award so that its benefits would in the future be as great as they are today.

Entirely apart from the prestige conferred by the making of such a benefaction, Dr. Reed rendered the Institute a singularly opportune service. Others who may have in mind gifts or bequests will, it is believed, feel that when a man of Dr. Reed's great ability and business experience placed such a bequest and award in the custody of the Institute, he was assured of its permanence and responsibility. No greater tribute has been paid to the basic ideas on which the Institute has developed.

Journal to be Published Monthly

Commencing with the issue of January, 1936, the Journal of the Aeronautical Sciences will be published monthly. This change was made by the Council so that more papers could be published during the coming year and greater service could be rendered members. The subscription price has been increased to five dollars a year to non-members ($6 foreign).

Meeting of Pacific Coast Section

A meeting of the Pacific Coast Section of the Institute was held in the Chamber of Commerce Building of Los Angeles on October 4th. The Secretary of the Institute was enabled to attend through the courtesy of United Air Lines, which extended its transportation facilities to him. 135 members and guests attended the dinner and the technical session which followed. Among those present were Donald W. Douglas, The Right Honorable the Earl of Cottenham, Glenn L. Martin, Anthony H. G. Fokker, R. H. Fleet, Robert Gross, Gerard Vultee, Dr. Clark B. Millikan, Professor Elliott G. Reid, Dr. W. Bailey Oswald, I. Machlin Laddon, and Harry A. Sutton. Three papers were presented, abstracts of which follow:

W. C. ROCKEFELLER
California Institute of Technology

High Altitude Air Transport Operations. The general performance methods were considered from the standpoint of constant thrust horsepower and extended to higher altitudes. The potential economy in time was considered along with the optimum length of flight for a proposed transcontinental schedule. From the air transport operator's standpoint, the importance lies in block-to-block time, and these calculations are based on this.

A. L. KLEIN AND J. E. LIPP
California Institute of Technology

Problems of the Pressure Cabin Airplane. This paper was a discussion of the problems arising in supercharging the cabin of an airplane. The paper was divided into several parts in which the following were discussed:

1. The source of the air for the cabin.
2. The manifolding and regulating system necessary for the functioning of the installation.
3. The safety measures necessary in the use of such an airplane commercially.
4. Developments which will be necessary before reliable operation can be expected.
5. A resume of the structural problems involved in carrying internal pressure in the cabin of an airplane.

WILLIAM BOLLAY
California Institute of Technology

The Performance of Rocket Planes. The performance of rocket planes was studied according to the methods of the aeronautical engineer. An analysis was made first of the power available, then of the power required. The power available is due to the forward thrust obtained by the ejection of burnt gases at high speed from the nozzle of a combustion chamber. The power required is to overcome the drag of the plane. The drag at velocities below that of sound can be closely estimated, being composed of the parasite drag and the induced drag. At velocities above that of sound, we have, in addition to these drags, the supersonic wave-resistance. Upon assuming a hypothetical airplane, reasonable assumptions are made for the thrust and drags. The equilibrium conditions for the forces on the airplane were set up and these differential equations were solved in a step-by-step method, thus giving the complete performance of the plane during its flight. The results indicate that very high speeds and altitudes could be reached, but that the range is, however, less than for present airplanes.

Classification of Articles

As an additional service to readers of the Journal, this section has been added wherein the leading articles from the various magazines and journals listed below have been classified by title under headings such as Meteorology, Aerodynamics, Power Plants and Fuels, etc.

Aero Digest
The Aeroplane
Aircraft Engineering
Aviation
Bulletin Technique du Bureau Veritas
Deutsche Luftwacht Luftwissen
Die Luftreise
Flight
Proceedings of the Institute of Radio Engineers
Journal of the Royal Aeronautical Society
Journal of Scientific Instruments
Journal of the Society of Automotive Engineers
L'Aeronautique
L'Aerotecnica
Luftfahrtforschung
National Geographic Magazine
Popular Aviation
Revista de Aeronautica
Revue du Ministere de L'Air
Western Flying

It is hoped that such a listing will save considerable time for the readers who are interested in only a few subjects of the entire Aeronautical field who may, by the use of this indexing service, cover their particular subject at a glance.

In subsequent issues of the Journal, various improvements upon the method of listing will be attempted and, of course, new publications will be added as soon as their exchanges are arranged. Any criticisms of or suggestions for improving this service will be welcomed by the staff.

Please turn to page 71

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Aerodynamics

Der Gross Windkanal der DVL (The giant wind tunnel of the D. V. L.). Deutsche Luftwacht Luftwissen, September, 1935.

Gallerie aerodinamiche per alte velocita (Aerodynamic galleries for high speed. L. Crocco, L'Aerotecnica, Vol. XV, Nos. 7–8, July–August, 1935.

L'influsso della limitazione della corrente sulle caratteristiche dei modelli di ali (Influence of the limitation of the air-stream on the characteristics of wing models). E. Pistolesi, L'Aerotecnica, Vol. XV, Nos. 7–8, July–August, 1935.

Les problèmes de l'aviation stratosphérique. Le refroidissement. (Problems of stratospheric aviation. The cooling problem.) C. Rougeron, L'Aeronautique, August, 1935.

Augenblicklicher Entwicklungsstand der Frage des Flügelflaterns (Present stage of development of the problem of wing flutter). H. G. Kussner, Luftfahrtforschung, Vol. 12, October 3, 1935.

Berechnung des Oberflächenreibungswiderstandes schneller flugzeuge (Calculation of the frictional resistance of the surfaces of fast airplanes). S. Hoerner, Luftfahrtforschung, Vol. 12, October 3, 1935.

Aerodynamischer Auftrieb bei uberschallgeschwindigkeit. (Aerodynamic lift at ultra-sonic velocity). A. Busemann, Luftfahrtforschung, Vol. 12, October 3, 1935.

Der 5 x 7 m. Windkanal der DVL (The 5 x 7 m. wind tunnel of the D. V. L.). M. Kramer, Luftfahrtforschung, Vol. 12, October 3, 1935.

The Characteristics of Plain Flaps. W. R. Andrews, Flight, Vol. XXVIII, No. 1401, October 31, 1935.

Tandem Wing Aeroplanes. J. H. Crowe, Aircraft Engineering, Vol. 7, No. 80, October, 1935.

Airplane Design

Sforzi interni indotti nelle cellule dei velivoli da errata regolazione e loro conseguenze (Internal strains on aircraft cellules caused by faulty regulation and their consequences). A. Vallerani, L'Aerotecnica, Vol. XV, Nos. 7–8, July–August, 1935.

Relation entre le tracé et la fatigue des organes des machines (Relation between the design of and the stress limitations of parts of machines). W. S. Burn, Bulletin Technique du Bureau Veritas, October, 1935.

Transformacion de un avion terrestre en un hidroavion de flotadores (Transforming a landplane into a seaplane). Felipe L. Babio, Revista de Aeronautica, Vol. IV, No. 43, October, 1935.

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Aeroplane Loading Conditions. S. P Osborne, Aircraft Engineering, Vol. 7, No. 80, October, 1935.

Plastic Materials for Aircraft Construction. Marcus Langley, The Aeroplane, Vol. XLIX, No. 1272, October 9, 1935.

Control Sensitivity. Otto C. Koppen, Aviation, Vol. 34, No. 10, October, 1935.

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The Heston Phoenix. Flight, Vol. XXVIII, October 24, 1935.

The Short Scion Senior. The Aeroplane, Vol. XLIX, No. 1275, October 30, 1935.

The Heston Phoenix. The Aeroplane, Vol. XLIX, No. 1274, October 23, 1935.

Les essais du gyroplane Breguet (Test of the gyroplane "Breguet"). (Photograph and description) L'Aeronautique, August, 1935.

Monomotor de bombardeo "Northrop Gamma 2-E" (The single engined bomber "Northrop Gamma 2-E"). Illustration and description) Revista de Aeronautica, Vol. IV, No. 43, October, 1935.

A French Heavy Bomber. Aircraft Engineering, Vol. 7, No. 80, October, 1935.

Flying Equipment. (Illustration and description) Aviation, Vol. 34, No. 10, October, 1935.

Glider and Glider Performance

The Sixth National Soaring Meet. Speed Westphal, Popular Aviation, Vol. XVII, No. 4, October, 1935.

The Second Stratosphere Expedition. The National Geographic Magazine, Vol. LXVIII, No. 4, October, 1935.

Glider Development in Germany. B. S. Shenstone and S. Scott-Hall, Aircraft Engineering, Vol. 7, No. 80, October, 1935.

Internat. Segelflug-Wettbewerb auf dem Jungfraujoch (International Soaring Contest on the Jungfraujoch). (Photographs and description). Die Luftreise, October, 1935.

Deutsche Segelflieger in Finnland (German gliders in Finland). Die Luftreise, October, 1935.

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A Study of the Cumulus Clouds. John B. Rathbun, Popular Aviation, Vol. XVII, No. 4, October, 1935.

Airports

Marine Air Terminals. George B. Post, Aero Digest, Vol. 27, No. 4, October, 1935.

Notes on the Selection and Design of Land Airports. A. P. Taliaferro, Jr., Aero Digest, Vol. 27, No. 4, October, 1935.

Airport Traffic Control. David S. Little, Aero Digest, Vol. 27, No. 4, October, 1935.

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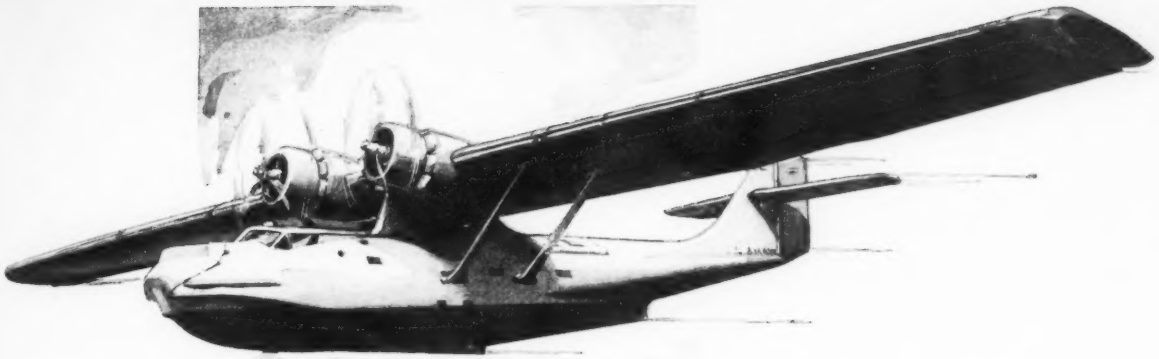
Please turn to page 72



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CONSOLIDATED AIRCRAFT CORPORATION, SAN DIEGO, CALIFORNIA

L'aviazione civile ad alta velocita (High speed civil aviation). G. Magaldi, L'Aerotecnica, Vol. XV, Nos. 7–8, July–August, 1935.

Les Liaisons Commerciales sur l'Atlantique.—II. Les traversées de l'Atlantique-Sud des avions et hydravions. III. Les voyages en dirigeable. (Commercial airlines across the Atlantic.—II. The crossings of the South Atlantic by airplanes and hydroplanes. III. Trips by airship.) de Brossard, Revue du Ministere de l'Air, Vol. 1, No. 10, October 15, 1935.

Development of Airway Beacons. H. C. Ritchie, Aero Digest, Vol. 27, No. 4, October, 1935.

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Commercial Aircraft. G. de Havilland, The Journal of the Royal Aeronautical Society, Vol. XXXIX, No. 298, October, 1935.

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At the Detroit Aviation Show. Max Karant, Popular Aviation, Vol. XVII, No. 4, October, 1935.

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Dive Bombing. H. F. King, Flight, Vol. XXVIII, No. 1400 October 24, 1935.

Les parachutes du personnel navigant (Parachutes of the flying personnel). A. Paricaud, L'Aeronautique, Vol. 17, No. 196, September, 1935.

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Ein Zepp fahrt 100mal ubers Weltmeer (A Zeppelin crosses the ocean one hundred times). Leonhard Adelt, Die Luftreise, October, 1935.

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Der Blick von oben (The view from above). Karl Lindemann, Die Luftreise, October, 1935.

Bemerkungen zu den Vorschriften für die Festigkeit von Flugzeugen (Januar 1935) (Comments on the regulations for stability of airplanes). Arthur Neesen and Alfred Teichmann, Deutsche Luftwacht Luftwissen, September, 1935.

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Recent Developments in Miniature Tubes. Bernard Salzberg and D. G. Burnside, Proceedings of The Institute of Radio Engineers, Vol. 23, October, 1935.

The Present State in the Art of Blind Landing of Airplanes Using Ultra-Short Waves in Europe. E. Kramar, Proceedings of The Institute of Radio Engineers, Vol. 23, No. 10, October, 1935.